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A PRELIMINARY SOIL CENSUS OF ALABAMA AND WEST FLORIDA

ROLAND M. HARPER

Received for publication February 28, 1917

The state of Alabama is readily divisible into fifteen or twenty geographical divisions, differing in geology, soil, topography, vegetation, and cultural features. The soils of each of these were described, as accurately as was possible at that time, by Dr. Eugene A. Smith, state geologist, in the sixth volume of the Tenth Census, 1884, and in his report on the agricultural features of Alabama, published by the State at about the same time. These reports include chemical analyses of soils from forty-nine localities, but these are too few to be thoroughly representative of so many regions, and indeed some of the regions are not represented at all.

Comparatively little has been added to our knowledge of the chemistry of Alabama soils since 1884; but since 1902 the United States Bureau of Soils has made more soil surveys in Alabama than in any other state—no doubt largely on account of the splendid foundation laid by Dr. Smith—and over half the area of the state, including the whole of some geographical divisions and parts of all the others, has now been mapped by that organization.

West Florida, which is that part of Florida west of the Apalachicola River, is here combined with Alabama to make an area of more regular shape and to illustrate some geographical principles better.¹ Four of the divisions of Alabama extend into it, and it also has four smaller divisions which are not represented in Alabama. Three government soil surveys cover parts of it, and the soils of the whole state were described by Dr. Smith in the same Tenth Census volume above mentioned.

The present census is based on all the government soil surveys for Alabama and West Florida published up to the end of 1916. As is doubtless well known to readers of this magazine, these reports, most of which cover a single county, say little or nothing about soil chemistry, but classify soils according to origin, color, moisture, texture, etc. Except for a few essentially non-agricultural types, such as rock outcrop, swamp, and coastal beach, each type of soil is given a generic or series name, usually of geographical origin, denoting its supposed history and color, and a specific or class name indicating its texture.

¹ Ever since Florida became a part of the United States there has been more or less talk of annexing West Florida to Alabama; and the Methodists long ago included it in their Alabama Conference. Sections 81 and 82 of Bulletin W of the United States Weather Bureau together cover exactly the same territory as this paper.

As the work has progressed during the last fifteen years or so, the number of series names has multiplied enormously, until now the distinctions between some of them are pretty hard to grasp. This makes it impracticable to use the soil series for statistical purposes, for surveys made of similar or neighboring areas several years apart may differ greatly in the number of series recognized. Or different men working in similar areas at the same time might easily interpret the same type of soil differently.

Although the nomenclature of the older surveys is revised from time to time, and long lists of changes can be found in some of the publications of the Bureau of Soils, particularly Bulletin 96 (the last of its series), published about the middle of 1913, there seems to be no special incentive for keeping the revision always up to date, and indeed in many cases it cannot be done properly without re-examining the areas at considerable expense and subdividing some of the types as originally mapped into two or more.

Unlike the similarly named geological formations, the soil series names have not come into general use among scientists, so that they would be meaningless to persons not familiar with the publications of the Bureau of Soils; but possibly this will be changed with the lapse of time. Soil series are also unlike geological formations in not having a fixed position in a linear series, which is another obstacle to averaging them up in statistics.

When texture classes alone are considered, regardless of series, most of the difficulties just mentioned are avoided. The texture classes can be arranged pretty well in a linear sequence, and their names (e.g., loamy fine sand, silty clay loam) are self-explanatory. The number of such classes is not likely to increase much, and although there will always be some uncertainties of identification, owing to the complete intergradation between different types, the errors will tend to balance when several surveys are taken together.

Each soil survey of a county or similar area lists the various soil types in order of area and gives the approximate acreage of each, as well as indicating their distribution on the map, on a scale of an inch to the mile. A person familiar with the geographical boundaries, therefore, can apportion the different soil types among the respective regions and compute the percentage of each with reasonable accuracy. (This has already been done in a general way for the whole United States and its larger divisions on pages 9-10 of Bulletin 96 of the Bureau of Soils, and in more detail for the state of Virginia in Bulletin 46 of the United States Department of Agriculture published a few months later.)

In these two government publications each of the larger divisions, like the Piedmont region and the coastal plain, is assigned a different set of series names, so that one can pick out the soils of each division pretty well without looking at the maps; but in this paper the divisions used are considerably smaller, and where a county includes parts of two or more of the divisions careful scrutiny of the map is required. When the areas of all the soils mapped in a given region are determined (it took about three days of steady

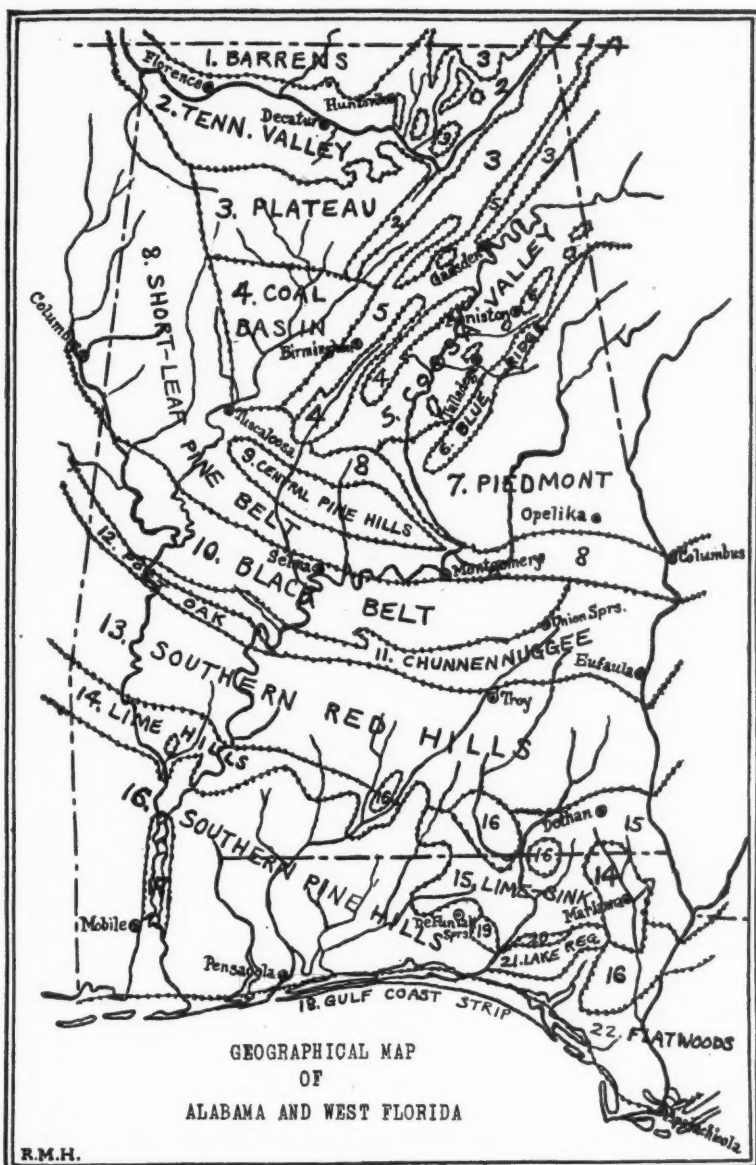


FIG. 1. MAP SHOWING THE REGIONS DESCRIBED HEREIN, AND ALSO THE PRINCIPAL RIVERS AND CITIES, TO ILLUSTRATE THEIR RELATIONS TO SOME OF THE GEOGRAPHICAL BOUNDARIES

Regions 17, 19 and 20, whose names are omitted from the map for lack of space, are the Mobile delta, the Knox Hill country, and Holmes Valley.

work to cover Alabama) they can be grouped together by texture classes, or by series if desired, and the percentages calculated.

The geography of Alabama and the northern part of Florida has been described by the writer in reports on forests published by the geological surveys of those states in 1913 and 1914, respectively, and the map used herewith shows very nearly the same geographical boundaries that were defined in those reports.² Some of these boundaries are so sharp that the transition from one region to the other is complete in less than a mile, but they have not all been located at a sufficient number of points to be mapped with perfect confidence. In some cases the boundary, though sharp enough, is too intricate to be drawn accurately on a map of this scale, and must therefore be generalized, as a topographic contour would be under the same circumstances. In other cases the transition from one region to another is so gradual that different persons might differ by a few miles in locating the boundary. On the present map no distinction is made between the well-defined and the indefinite boundaries, but some information on these points may be gathered from the geographical reports just mentioned, and from some of the soil surveys. One of the least satisfactory boundaries at the present time is that between the lime-sink region and the southern pine hills, principally because of lack of opportunity to trace out all its sinuosities. But fortunately this uncertainty does not materially affect the soil statistics, for these two regions do not differ as much in soil as they do in topography. Two divisions of the central pine belt of Alabama that were kept separate in 1913 are here combined, because their differences are mainly geological, and it is almost impossible to separate them by their soils alone.

Brief sketches of the geographical divisions now follow, beginning with the northernmost. The first seven belong to the highlands, or mineral region, and the rest to the coastal plain. The descriptions are on the following plan: area in Alabama and general distribution elsewhere, geology, topography, principal series and classes of soils in order of area, percentage of evergreens in the forests, commonest native trees in order of abundance, percentage of improved land in 1880, and the expenditure for fertilizers in 1909 per acre of improved land in 1910. The relative extent of the different soil series is not considered very important, for reasons previously mentioned, but may be of interest to persons familiar with the government classification, and to others who can easily remember some of the more important series, such as the reddish clayey "Orangeburg," the yellowish sandy "Norfolk," and the black mucky "Portsmouth."

The statistics of vegetation and agriculture are given as a contribution toward correlating such features with soil texture. Those who have investigated soils from a chemical standpoint have long known that deciduous trees

² A similar but less detailed map of Alabama and some of the same agricultural statistics were used by the writer in the Proceedings of the Society of American Foresters, vol. 11, p. 208-214. 1916.

in general and certain species in particular characterize the richer soils, and also that the more fertile the soil the larger proportion of it is cultivated and the less the expenditure for fertilizers.³ And regardless of chemical composition, the soils of finest texture are generally the most productive, except that the clays and mucks are often inferior to the loams and silt loams, on account of imperfect aeration.⁴ The vegetation statistics are taken with slight modification from the geographical reports cited. The statistics of improved land are computed from the 1880 census because that was more accurate than any earlier one, and because after that differences in original fertility were being overcome more and more by the use of fertilizers. The statistics of fertilizer consumption have been computed from the 1910 census, because that is the latest.

In these regional sketches, and also in the table following them, some soil classes which do not differ much are lumped together for the sake of simplicity, e.g., rock outcrop and rough stony land, stony, gravelly and cherty loam, shale and slate loam, and swamp, muck, and meadow.⁵

THE REGIONS

1. The "barrens" of the Tennessee valley, a continuation of the Highland Rim of Middle Tennessee, cover about 800 square miles in Alabama. The geological formation is mostly Keokuk chert, of Mississippian age, with strata horizontal or nearly so. The soils are mainly grayish or yellowish. The topography is comparatively level except in the vicinity of streams, which have cut valleys proportional to their size. The whole area in Alabama is covered by three soil surveys, in which the soils are referred mainly to the Clarksville series, with small amounts of Decatur, Hagerstown, etc. Silt loam, stony and gravelly loam, and clay loam cover about 99 per cent of the area. Silt loam is relatively more abundant here than in any other part of the state.

About 30 per cent of the forest is evergreen. The commonest trees are short-leaf (loblolly) pine, red oak, sweet gum, short-leaf pine, post oak, willow oak, and beech. About 25 per cent of the area seems to be cleared at present, and the annual expenditure for fertilizers probably does not exceed 50 cents an acre, though no accurate statistics can be given for such a small area, which does not cover the whole of any county.

³ See Harper, R. M. Vegetation and soils. *In Science*, n. s., vol. 42, no. 1084, p. 500-503. October 8, 1915.

⁴ In this connection see Cannon, W. A., and Free, E. E. The ecological significance of soil aeration. *In Science*, n. s., vol. 45, no. 1156, p. 178-180. February 23, 1917.

⁵ In the Bureau of Soils publications from the beginning the term "meadow" has been employed regardless of ordinary usage to designate almost any land subject to overflow from small streams, whether it bears meadow vegetation or not (in the South it is usually wooded). But many soils which in the earlier reports were called simply Swamp or Meadow are now assigned to definite series and texture classes, so that the percentage of swamp land as determined from the soil surveys is only a rough approximation.

2. The Tennessee valley proper lies on both sides of the Tennessee River, and has an area of about 4100 square miles in Alabama, to which this particular type of country is chiefly confined. The greater part of the area is underlaid by horizontal strata of Mississippian (Subcarboniferous) age, but at the southeastern edge there is a long straight narrow valley of folded and faulted Ordovician and Silurian rocks, very similar to the Coosa valley described farther on. Much of the rock is limestone, and the soils are prevailingly reddish. The central part of the area is comparatively level, but near its edges are many ridges and rocky slopes. The greater part is now covered by soil surveys. The leading soil series are the Clarksville, Decatur, Huntington and Hagerstown, and the texture classes silt loam, stony and gravelly loam, clay loam, loam, rock, silty clay loam, and fine sandy loam. Evidently there is not much contrast in soil texture between this region and the preceding, but the vegetation and agriculture seem to indicate considerable chemical difference.

About 16 per cent of the original forest was evergreen. The commonest trees at present seem to be cedar, sweet gum, loblolly pine, red oak, scaly-bark hickory, sycamore, willow and beech. About 30 per cent of the area was "improved" in 1880, and the average expenditure for fertilizer in 1909-10 was about 25 cents an acre.

3. The plateau region, a continuation of the Cumberland plateau of Tennessee and Kentucky, covers about 3100 square miles in Alabama, where most of it goes by the name of Sand Mountain. Erosion has isolated several mesa-like outliers, of which Lookout Mountain is the largest. The rocks are nearly all sandstone of the lowest Coal Measures, and the strata are essentially horizontal. The surface is comparatively level for a mountain region, but stands several hundred feet higher than the valleys on either side, making it somewhat difficult of access. Most of the area has been covered by soil surveys, and about 98 per cent of the soils, not counting rock outcrop, are referred to the DeKalb series (named for DeKalb County, Alabama). The prevailing soil classes, are fine sandy loam, sandy loam, rock, stony loam, loam, and silt loam. There is more fine sandy loam here than in any other of the highland regions.

About 45 per cent of the forest is evergreen. The commonest trees are loblolly pine, short-leaf pine, post oak, red maple, poplar, sweet gum, cliff pine, white oak, chestnut oak and dogwood. Only about 8 per cent of the land was cultivated in 1880, and in 1909-1910 the farmers spent about a dollar an acre for fertilizers; all of which indicates soils below the average in fertility.

4. The coal basin region covers about 3300 square miles, and does not extend into any of the neighboring states. The rocks are a little younger than those of the plateau, more shaly, and more folded and faulted in some places. The topography is more dissected, mainly on account of the rocks being softer. The prevailing soil series are DeKalb and Hanceville, and the

texture classes silt loam, shale loam, fine sandy loam, very fine sandy loam and stony loam. Shale loam is more abundant here than in any other part of the state.

About 40 per cent of the trees are evergreen. The commonest species are loblolly pine, cliff pine, short-leaf pine, beech, long-leaf pine, red oak, white oak, sweet gum, red maple, post oak, poplar and dogwood. Only about 10 per cent of the area was cultivated in 1880, and even now coal mining employs about as many people as farming. The expenditure for fertilizers in 1909-1910 was about 75 cents an acre.

5. The Coosa valley, the southwestern extremity of the great Appalachian valley, which is over 1000 miles long, includes about 4000 square miles in Alabama, more or less interrupted by outliers of the neighboring mountain regions. The rocks are all Paleozoic, mostly older than Carboniferous, and nearly everywhere folded and faulted, making many narrow longitudinal ridges and minor valleys. Both limestone and sandstone are common. The principal soil series as mapped are Clarksville, Decatur, Huntington, Fort Payne,⁶ and Hagerstown, and there are at least a dozen others. Gravelly, stony and shale loams make up nearly half the total, and next in importance are loam, silt loam, clay loam, clay, and fine sandy loam. This region leads all the rest in stony loam and loam, and all the other highland regions in clay.

Evergreens make up about 45 per cent of the forest. The commonest trees seem to be loblolly, long-leaf, and short-leaf pines, sweet gum, post oak, red oak, black-jack oak, poplar, red maple, white oak, water oak and willow oak. About 20 per cent of the land was improved in 1880, and 64 cents an acre was spent for fertilizers in 1909-1910.

6. The Blue Ridge is represented in Alabama by a narrow strip trending northeast-southwest, and a few outlying ridges and peaks, probably not over 400 square miles in all. The rocks are pretty old and highly metamorphosed, and mostly siliceous. The topography is typically mountainous, and we find here the highest mountain in the state, Cheaha, 2400 feet above sea-level. Most of the area is covered by soil surveys, and the soils are referred chiefly to the Talladega⁷ and DeKalb series. The leading texture classes are slate loam, rough stony land, gravelly and stony loam, and silt loam. The first two are relatively more abundant here than in any other part of the state.

About half the trees are evergreen, and the commonest ones are long-leaf pine, short-leaf pine, black-jack oak, black oak, loblolly pine and chestnut oak. The area is too narrow for census statistics, but there is very little agriculture, on account of the rough topography.

⁶ Named for Fort Payne, Alabama, which is in this region; but most of the original Fort Payne soils in Alabama are now referred to the Clarksville series.

⁷ This is one of the few cases where the soil series name corresponds with the geological formation name.

7. The Piedmont region covers about 5000 square miles in Alabama, and extends northeastward to Pennsylvania. Its rocks are metamorphic or crystalline, and largely granitic. The topography is everywhere hilly, and there is running water on practically every square mile. About half the soils are referred to the Cecil series, and next in importance are the Louisa, Congaree and Talladega. The leading types are sandy loam, stony loam, slate loam, clay loam, loam, stony and gravelly sandy loam, and fine sandy loam. Some shade of red is the prevailing color, and minute flakes of mica are very characteristic. There is more sandy loam and more swamp than in any of the regions previously described.

About 45 per cent of the present forest is evergreen. The commonest trees seem to be long-leaf, loblolly and short leaf pines, sweet gum, black-jack oak, poplar, red oak, post oak, red maple, bay and dogwood. About 24 per cent of the acreage was cultivated in 1880, and thirty years later the farmers were spending 95 cents an acre annually for fertilizers.

8. The innermost division of the coastal plain in Alabama is the short-leaf pine belt. Including the Eutaw belt (which was separated before) it covers about 6600 square miles in Alabama, and extends northwestward across Mississippi into Tennessee. It is underlaid by clayey non-calcareous Cretaceous strata of the Tuscaloosa and Eutaw formations, and is moderately hilly and well watered. At least 16 different soil surveys touch this region, and about twenty soil series have been distinguished, of which the principal ones are the Orangeburg, Guin, Norfolk and Ruston. The leading texture classes are fine sandy loam, sandy loam, gravelly sandy loam, loam and gravelly loam.

About half the trees are evergreen. The commonest are loblolly, short-leaf, and long-leaf pines, sweet gum, bay, water oak, poplar, beech, willow, post oak, white oak, red maple, dogwood, willow oak and cypress. The soils seem to be a little below the average in fertility, for only 16 per cent of the area was "improved" in 1880, and the expenditure for fertilizers in 1909-1910 averaged 75 cents an acre.

9. The central long-leaf pine hills, about 850 square miles in extent, are surrounded by the short-leaf pine belt, and might be treated as a high and dry extreme of it. The underlying strata are of the Tuscaloosa formation, and composed of clay, sand and pebbles in varying proportions. It is a high and rather hilly region, almost mountainous in places, with many creeks and branches. It has been completely covered by soil surveys, but one of those is so old that it does not give much detail. The soil series recognized are the Orangeburg, Susquehanna, Norfolk, Guin, Ruston, and one or two others, and the leading types are sandy loam, gravelly sandy loam, gravelly loam, loamy sand and fine sandy loam. The first four are more prevalent here than in any other part of the coastal plain in Alabama.

Evergreens make up about 60 per cent of the forest. The commonest trees

are long-leaf pine, loblolly pine, black-jack oak (two kinds), short-leaf pine, turkey or upland willow oak, bay, red oak, red maple, poplar, and dogwood. The region does not cover as much as half of any one county, so that no agricultural statistics are available, but probably not over 15 per cent of it is under cultivation even yet, on account of the rough topography and rather poor soil.

10. The black belt or central prairie region, covering about 4300 square miles in Alabama, is one of the most distinct and sharply defined divisions of the coastal plain. It has no counterpart farther east, but extends northwestward across Mississippi, and reappears in Texas. It coincides almost exactly with the area of the Selma Chalk or Rotten Limestone, one of the Cretaceous formations. Most of the soil is some shade of gray. The topography is undulating, not very hilly, and water is rather scarce, as in many other fertile and calcareous regions. The summers are drier here than in any other part of the coastal plain of Alabama, a fact which may have some bearing on the soil conditions.⁸

The soils have been referred to about twenty series, of which the most extensive are the Houston,⁹ Norfolk, Orangeburg, Susquehanna, Oktibbeha, Waverly, Yazoo, Ocklocknee, and Trinity. Over half the soil is classed as clay, and over one-fifth as fine sandy loam. The only other type making over 3 per cent of the total is loam.

A part of this region, possibly 10 per cent, was treeless when first discovered. About 30 per cent of the trees in the remaining forests are evergreen, but this figure decreases northwestward, with the drier summers. The commonest species seem to be loblolly pine, sweet gum, post oak, short-leaf pine, long-leaf pine, red oak, hackberry, willow oak, cedar, cottonwood, willow, elm and sycamore. About 45 per cent was cultivated in 1880, and only 35 cents an acre was spent for fertilizers in 1909-1910, indicating soils above the average in fertility, for the coastal plain especially.

11. The Chunnennuggee Ridge, or blue marl region, is chiefly confined to Alabama, where it covers about 2300 square miles. It is underlaid by marly strata of the Ripley formation (Upper Cretaceous), and has a moderately hilly topography, with more streams than the black belt. The soil series are Norfolk, Susquehanna, Orangeburg, Ruston, Kalmia, and nine or ten others, and the principal texture classes are sandy loam, fine sandy loam, sand, clay, fine sand, meadow, etc.

⁸ See Geol. Surv. Ala., Monog. 8, p. 19, 24 (footnotes). 1913.

⁹ This series name was first used in the reports on Perry County, Alabama, and the "Brazoria area," Texas, about 14 years ago, and is apparently derived from Houston, Texas, which is in a region quite different geologically and topographically from the black belt of Alabama and Mississippi (which however does have a counterpart in the interior of Texas). If it should ever seem desirable to separate the soils of the undulating Cretaceous black belt from those of the level Neocene coast prairie an appropriate name would be Noxubee, which is the name of a large creek in the black belt in Alabama and Mississippi and of a county in Mississippi.

About 45 per cent of the trees are evergreen, and the commonest species are loblolly, long-leaf and short-leaf pines, sweet gum, spruce pine, bay, post oak, red oak, water oak, poplar, and willow. This too is a more fertile region than the average of the coastal plain, and about 40 per cent of the area was classed as improved land in 1880. The expenditure for fertilizers in 1909-1910 was 79 cents an acre.

12. The post-oak flatwoods is a peculiar region almost confined to Alabama and Mississippi, and covering about 335 square miles in Alabama. It is underlaid by one of the oldest of the Eocene formations, a grayish non-calcareous clay at the surface, passing downward, in some places at least, into a sort of black shale. The topography is comparatively level, as the name implies, and streams are scarce. Only one of the Alabama soil surveys touches this region, and that (Sumter Co.) was published about 12 years ago. But the adjoining county of Noxubee in Mississippi, surveyed six years later, has been combined with it here to make the statistics more accurate. The prevailing soil series are the Lufkin,¹⁰ Norfolk, Pheba,¹¹ Orangeburg, and Waverly, and the texture classes fine sandy loam, clay, clay loam, loam, sandy loam and silt loam. There seems to be proportionately more clay loam and loam here than in any other division of the coastal plain.

About 45 per cent of the trees are evergreen. The commonest are loblolly and short-leaf pine, post oak, sweet gum, red oak, water oak, willow oak and beech. The region is too narrow to apply census statistics to, but it is not cultivated much, on account of the "cold" stiff clayey soil and the scarcity of good water.

13. The southern red hills is one of the largest divisions of the coastal plain, extending from South Carolina to Mississippi and reappearing farther west. It covers about 8000 square miles in Alabama. The underlying rocks are Eocene, but most of the surface material is a reddish sandy clay which may be of much later age. The topography varies from nearly level to hilly and even mountainous. (The "mountains" extend from Monroe County northwestward into Mississippi, and are high enough to be pierced by a railroad tunnel in each state, apparently the only tunnels in the whole coastal plain.) Streams are common, most of them bordered by swamps. About fifteen soil series have been recognized, of which the principal ones are the Orangeburg, Norfolk, Susquehanna, Greenville,¹² Kalmia, and Ruston. By texture the soils are classed as fine sandy loam, sand, sandy loam, fine sand, swamp, clay, etc.

Evergreens are estimated to make 58 per cent of the forest. The commonest trees are long-leaf, loblolly and short-leaf pines, sweet gum, spruce pine, red oak, water oak, bay, magnolia and poplar. About 17 per cent of the

¹⁰ Named for Lufkin, Texas.

¹¹ Named for Pheba, Mississippi, which is in this same flatwoods belt.

¹² Named for Greenville, Alabama, which is in this region.

area was cleared in 1880, and thirty years later the farmers were spending \$1.20 per acre annually for fertilizers.

14. The belt known as the lime hills extends from Wayne County, Mississippi, to Conecuh County, Alabama, and reappears in West Florida as the Marianna red lands. It covers about 1300 square miles in Alabama and 450 in Florida. The underlying rock is chiefly limestone of Upper Eocene age, but the surface is largely red loam. The topography is moderately hilly, with a few caves and natural bridges, but with plenty of streams and few or no ponds. The soil series are Orangeburg, Norfolk, Greenville, Ruston, Susquehanna, Ocklocknee, and seven or eight others, and the texture classes fine sandy loam, sandy loam, swamp, sand, coarse sandy loam, stony clay, etc. The last is more prevalent here than elsewhere in the coastal plain, and the same may be said of rock outcrop.

The proportion of evergreens has been estimated at 44 per cent in Alabama and 49 per cent in Florida. The commonest trees seem to be loblolly, long-leaf, short-leaf and spruce pines, sweet gum, red oak, beech, magnolia, bay, dogwood, cedar, water oak, black-jack oak, white oak and cypress. No agricultural statistics are available, on account of the narrowness of the area, but agriculture has long been the leading industry.

15. The lime-sink region extends from Covington County, Alabama, and Walton County, Florida, northeastward about to the Savannah River, and covers about 1300 square miles in Alabama and 1600 in Florida. The underlying formation is limestone of the Vicksburg formation, more or less silicified and nearly everywhere covered with later clays and sands. The topography is comparatively level, and diversified by many shallow ponds and a few lime-sinks. Streams are not abundant, much of the drainage being subterranean. There are only two soil surveys for this region as yet (Covington County, Alabama, and the "Marianna area," Florida), and both of those include parts of two or more other regions, so that we are not in a position to give very accurate statistics of the soils. Over half are referred to the Norfolk series, and the rest are Tifton, Myatt, Kalmia, etc. Fine sandy loam, sandy loam, swamp, sand and fine sand make up about 99 per cent of the total.

About 70 per cent of the trees are evergreen. The commonest trees are long-leaf pine (about 45 per cent), pond cypress, slash pine, loblolly pine, forked-leaf black-jack oak, black gum, turkey oak, bay, red oak, sweet gum and magnolia. Very little of the land, possibly 3 per cent, was classed as "improved" in 1880, but by 1910 about 26 per cent was cultivated, with the aid of about \$1.40 worth of fertilizers per acre per year.

16. What may be called the southern pine hills extends from near the Savannah River in Georgia with some interruptions to Louisiana, and covers about 5000 square miles in Alabama and 3800 in West Florida. Within a

few hundred feet of the surface there are only unconsolidated non-calcareous sandy and clayey strata very similar to those of the central pine hills, but of much later age, probably not older than Miocene. The topography is hilly or undulating to flat, with running water on nearly every square mile, and many shallow ponds besides. Very few of the ponds are deep enough to hold water throughout the year.

The soils have been referred to about twenty series, of which the Norfolk covers over half the area. Next in importance are the Ruston, Orangeburg, Kalmia, Tifton, and Myatt. The principal texture classes are fine sandy loam, sand, sandy loam, fine sand, loamy sand and swamp.

The proportion of evergreens has been estimated at 74 per cent in Alabama and 76 per cent in Florida. There is more long-leaf pine than all other trees combined, and where undisturbed by lumbermen it forms beautiful open park-like forests, with very little underbrush. Other common trees, growing mainly in swamps and ponds or on sandy ridges, are slash pine, forked-leaf black-jack oak, loblolly pine, bay, pond cypress, turkey oak, and black gum.

The development of agriculture in this region has been rapid in recent decades. The improved land jumped from about 1 per cent in 1880 to 8 per cent in 1910. This increase would have been impossible without the aid of fertilizing materials from the mines of Florida, Germany, Chile, etc., the expenditure for which increased from 95 cents an acre in 1879-1880 to \$2.09 in Alabama and \$2.33 in Florida in 1909-1910.¹³

17. The Mobile delta comprises the swamps of the Mobile and Tensaw Rivers (continuations of the Tombigbee and Alabama) within the influence of tide-water, an area of about 300 square miles. This delta is long and narrow, and occupies what appears to be a "drowned valley" in the pine hills. Its lower extremity at present is just about opposite the city of Mobile, and is slowly moving seaward, but will hardly reach the mouth of Mobile Bay for several thousand years. The whole area is inundated almost every spring by muddy waters carrying the cream of the soil from an area of about 40,000 square miles in Georgia, Alabama and Mississippi, some of which is very fertile. The Apalachicola River has a similar but smaller delta, shown on the soil map of Franklin County, Florida, but it is mainly on the east side of the river, in Middle Florida, and has not been counted in the following statistics. The Mobile delta is nearly covered by the soil surveys of Baldwin, Mobile, and Clarke Counties, Alabama, in which nearly half its area is classed as Swamp, and the rest chiefly as "Ocklocknee¹⁴ clay" and "Ocklocknee silt loam."

¹³ For a discussion of the influence of imported fertilizers on agriculture in the pine lands see *Jour. Geogr.*, vol. 15, p. 42-48. October 1916; and *Geogr. Rev.*, vol. 2, p. 366-367. November, 1916.

¹⁴ This series name, derived from the Ocklocknee River of Florida, which rises among the pine hills of South Georgia (where it is spelled Ochlocknee) and is seldom muddy, does not seem very appropriate for the alluvium of large rivers that are always muddy.

About 13 per cent of the trees are evergreen. The explanation of the occurrence of any evergreens at all in such fertile soil is probably that lack of aeration limits the availability of the potassium compounds, and thus compels some of the trees to economize by keeping their leaves more than one season. The commonest trees seem to be black gum, cypress, bay (this is the commonest evergreen, chiefly toward the lower end of the delta, where the seasonal fluctuation of the water is at a minimum and therefore the aeration of the soil least), willow, sweet gum, red maple, and cottonwood. There is no agriculture except perhaps at the extreme edges of the swamps.

18. The Gulf coast strip is a narrow belt of islands, dunes and marshes along the coast from Middle Florida to Mississippi. About 65 per cent of its area is classed in the soil surveys as coastal beach, sand-hill, etc., and 27 per cent as tidal marsh. About 80 per cent of the trees are evergreen. The commonest are spruce pine (a different species from the one in the interior of the coastal plain), long-leaf-pine, slash pine, live oak (two species), forked-leaf black-jack oak, turkey oak and cedar. There is practically no agriculture.

19. The Knox Hill country is an area of about 50 square miles lying between the lime-sink region and the pine hills in Walton County, Florida. Its geology is not well known, but the underlying formations are believed to be at least in part Miocene. It is a region of reddish clayey hills and running water, strongly resembling some parts of the central short-leaf pine belt of Alabama. In some places the soil is so clayey that the roads have to be surfaced with sand or poles, which is very unusual in Florida. There is no soil survey for this region yet, but much of the soil would probably be called "Orangeburg fine sandy loam" or something of the sort.

A majority of the trees are evergreen, and the commonest species are loblolly pine, short-leaf pine, red oak, long-leaf pine, dogwood, magnolia, sweet gum, holly, spruce pine, beech, white oak, bay, black-jack oak and black gum. Agriculture has been an important industry here for nearly a century. At present probably not more than 25 per cent of the area is under cultivation, but the cultivated acreage is said to have been larger before the Civil War, when commercial fertilizers were unknown, and farming in Florida was confined to the few areas of naturally fertile soil.¹⁵

20. Holmes Valley is an area of 25 or 30 square miles lying between the lime-sink region and that next to be described, in Washington County, Florida. It resembles the Knox Hill country in being a red hill region surrounded by sandy pine lands, but differs in having less running water and coarser and less clayey soils. The soil is evidently quite fertile, however, for most of it is or has been cultivated; and in the sixth volume of the Tenth Census (page 225) Dr. Smith cites a case where a tract of land in this region was producing nearly a bale of cotton to the acre in 1880 after being culti-

¹⁵ See Geogr. Rev., vol. 2, p. 363. November 1916.

vated for thirty-five years, without fertilizers. From the abundance of sweet gum, which is common in some known phosphatic soils, it is reasonable to suppose that the soil of this region is well supplied with phosphorus, though neither physical nor chemical analyses are available yet.

Evergreens are less abundant here than in the preceding region, and perhaps not in the majority. The commonest trees seem to be loblolly pine, sweet gum, long-leaf pine, black gum, dogwood, bay, beech, water oak, white oak, magnolia, red oak, post oak and hickory.

21. The West Florida lake region has an area of perhaps 350 square miles. Nothing definite is known about its geology, the surface being almost completely covered with sand. The surface is comparatively level except for being pitted with numerous approximately circular depressions from several to a few hundred acres in extent, most of them containing lakes which never dry up.

A part of the region is included in the soil survey of the "Marianna area," and the prevailing soil is classed as "Norfolk sand." About 75 per cent of the trees are evergreen, and long-leaf pine and forked-leaf black-jack oak constitute the bulk of the forest. No census statistics are available, but there is very little agriculture yet, on account of the very sandy soil.

22. The Apalachicola flatwoods region extends from Bay County to Wakulla County, Florida, just back of the coast strip, and about 1200 square miles of it lies in West Florida. No geological formations older than Pleistocene are known here, and the soil is nearly all sand, where it is not covered by peat, muck or something else. The surface is nearly everywhere flat and damp. The soil survey of Franklin County, Florida (published last fall), covers part of this region, and although that county is mostly in Middle Florida, there is no reason to suppose that its soils are not equally typical of the West Florida portion.

The principal soil series are Hyde, Plummer, Norfolk, Portsmouth, and Leon, and the texture classes fine sand, swamp, loamy fine sand, etc. There is more fine sand here than in any region previously described. About 75 per cent of the trees are evergreen, but this figure would be higher if the Apalachicola River swamps were excluded. The commonest trees are long-leaf pine, pond cypress, slash pine, black pine, bay, black gum, sweet gum and red maple. Less than 3 per cent of the area is under cultivation. The expenditure for fertilizers in Franklin County in 1909-1910 was about a dollar an acre, but it would be much greater if anything more than a few of the richest spots were cultivated.

STATISTICS

The following tables show the percentage of each type of soil in each of the regions above described, except some of the smallest ones, for which no statistics are available. One table is for the highlands and one for the coastal

plain, and the averages are given for each of these major divisions as a whole. In each table the highest figure in each row is printed in heavier type, to show what classes of soil are more abundant in a given region than in any other. The percentages are given only to the nearest integer, to save space and also to avoid making them appear more accurate than the facts warrant. Percentages below 0.5 are therefore represented by 0. The soil classes are arranged approximately in order of texture, the coarsest first.

At the bottom of each table the statistics of evergreens, improved land, and fertilizers already given are brought together, and also summarized for the two major divisions.

TABLE 1
Soils of highlands in Alabama

SOIL CLASSES	REGIONS						
	1. Barrens	2. Tenn. valley	3. Plateau	4. Coal basin	5. Coosa valley	6. Blue Ridge	7. Piedmont
Rock outcrop, etc.....		9	10	5	2	23	0
Fine sand.....		0					0
Stony, gravelly or chert loam.....	36	18	8	7	46	19	20
Shale or slate loam.....			4	27	2	54	14
Stony or gravelly sandy loam.....			2	2	2		9
Stony silt loam.....			1				0
Coarse sandy loam.....							1
Sandy loam.....		0	19		1	0	24
Fine sandy loam.....		6	39	15	5	0	5
Very fine sandy loam.....				10			1
Loam.....		12	7	0	15		10
Silt loam.....	44	28	5	35	10	3	15
Silty clay loam.....	1	7					1
Clay loam.....	18	18			9	1	11
Stony clay.....		0			0		2
Clay.....	0	1	3		6		0
Swamp or meadow.....		1	1		1		2
Percentage of evergreens.....	30	16	45	40	45	50	45
Percentage of improved land, 1880.....	?	30	8	10	20	0	24
Expenditure for fertilizers per acre, 1909-10 (dollars).....	?	0.25	1.00	0.75	0.64	?	0.95
							0.63

Some comments on these tables will be of interest. It is, of course, not at all surprising that rock outcrops should be far more extensive in the highlands than in the coastal plain, for the strata of the latter, being much younger, have never been subjected to enough pressure from overlying materials to harden them into rock. What few rocks do occur in the coastal plain are chiefly the result of cementation of sand by iron oxide, or of deposition of

calcium carbonate by marine organisms. The only rock outcrop in the whole coastal plain of the United States reported in Bulletin 96 of the Bureau of Soils (page 301) is 384 acres of limestone in the "Marianna area," Florida, and this forms the basis of the first figure in column 14. But the "Lauder-

TABLE 2
Soils of coastal plain in Alabama and West Florida

SOIL CLASSES	REGIONS												Whole coastal plain		
	8. Short-leaf pine	9. Central pine hills		10. Black belt	11. Chunnennuggee	12. Post oak	13. Red hills		14. Lime hills	15. Lime-sink	16. So. pine hills	17. Mobile delta		18. Coast strip	22. Apalachicola
Rock outcrop.....								0							0
Gravelly sand.....							1			2					0
Coarse sand.....	3			3			1	2	0		0				1
Sand, sand-hill, coastal beach.....	3	2		17	2	21	9	12		23	65				12
Fine sand.....	0	1	2	7		8	2	9		8	0		82		6
Loamy sand (fine or coarse).....		15		0		3	0			7		1	4		3
Stony or gravelly loam.....	5	19		1			0								2
Stony or gravelly sandy loam.....	10	21		3		1	2			2					4
Coarse sandy loam.....	0			0		0	3	0							0
Sandy loam.....	21	33	2	24	4	18	14	21		14					16
Fine sandy loam.....	37	7	22	23	35	37	45	45		34	1				32
Very fine sandy loam.....	0			5											0
Loam.....	5		6		9	1	2			2	3				3
Silt loam.....	4				4	0	2			1	17				2
Silty clay loam.....	0			0											0
Clay loam.....	1		2		9	0	1				3				1
Stony clay.....						1	3								0
Clay (including black clay).....	4		60	11	33	4	2			1	28				11
Swamp, meadow, muck, etc.....	5	4	2	6	3	5	13	13		6	47	7	14		6
Tidal marsh.....											127				0
Percentages of evergreens..	50	60	30	45	45	58	47	70		75	13	80	75		59
Improved land, 1880.....	16	?	45	40	?	17	?	?		1	0	0	1		14
Expenditure for fertilizers per acre, 1909-10 (dollars).....	0.75	?	0.35	0.79	?	1.20	?	1.40		2.18	0	?	1.04		0.93

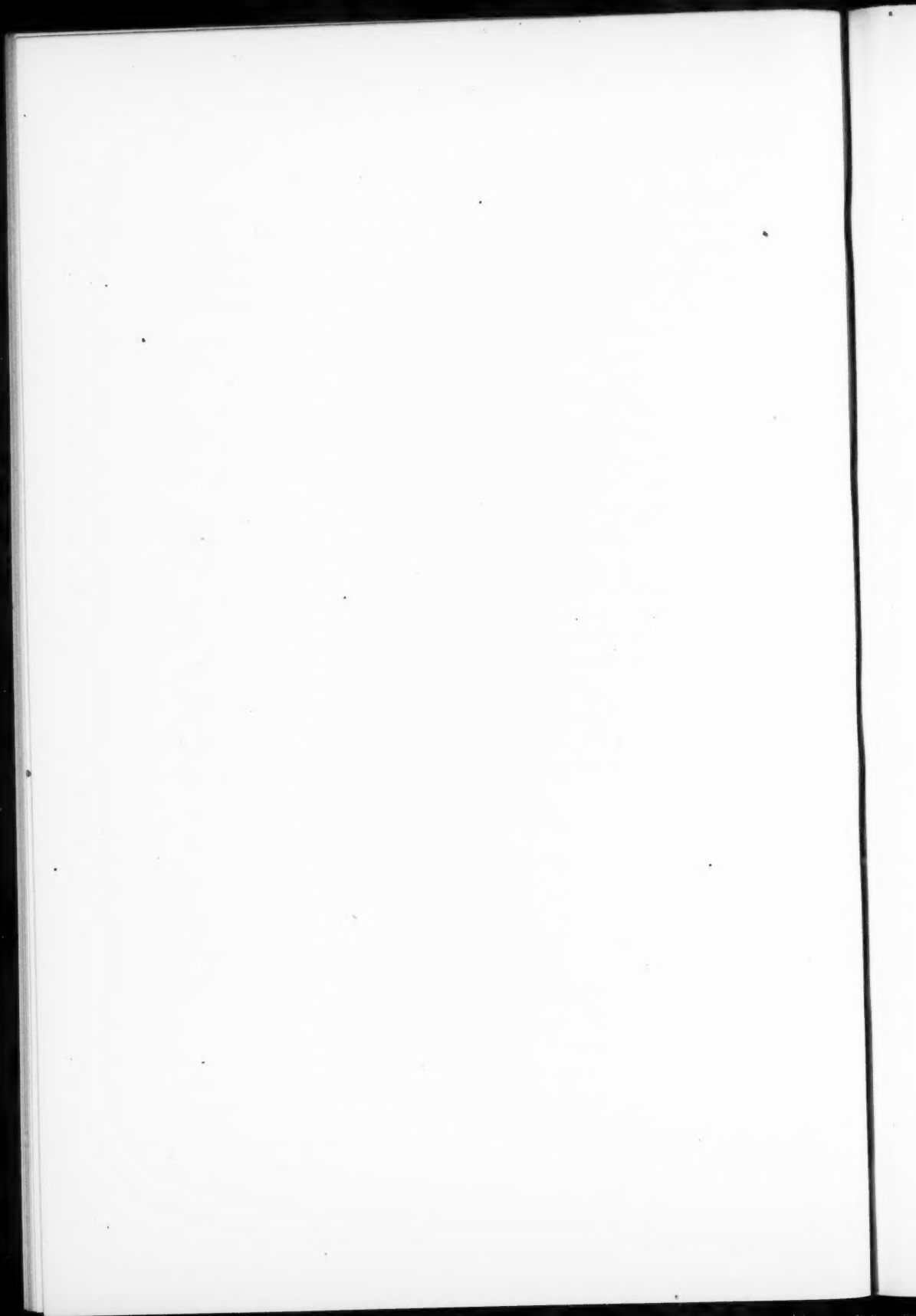
dale stony clay" in the southern part of Clarke County, Alabama (not that in the northern part) is practically the same thing, and belongs to the same region; and there are many rock outcrops too small to map in other divisions of the coastal plain.

Pure sand as a soil type is almost wanting in the highlands, but fairly common in the coastal plain. The various stony loams, silt loams, and clay loams are common in the highlands, but scarce south of the central pine belt, while the sandy loams are naturally commonest southward. There is more pure clay soil in the coastal plain than in the highlands, a fact not easily explained in a few words.

It has long been known that swamps are more extensive in the coastal plain than in the interior, but that fact has perhaps never been shown statistically before. Although the percentages for swamps cannot be regarded as very accurate, for reasons given on an earlier page, it is unquestionable that they are several times as prevalent in the coastal plain as in the highlands; a fact doubtless correlated with the "immaturity" of the topography, and also with the heavier summer rainfall toward the coast, which counterbalances the evaporation to a considerable extent.

The evergreen percentages range from 13 in the Mobile delta to 80 in the coast strip, and average about 52 for the whole area mapped. The highest percentage of improved land is in the black belt, and the highest expenditure for fertilizer in the southern pine hills.

The correlations between evergreens, improved land and fertilizers are very significant, especially if we disregard those regions where agriculture is undeveloped on account of rough topography or periodical inundation, or better still, consider only the two major divisions, thus eliminating local irregularities. The highlands, having richer and finer soil on the average than the coastal plain, have relatively more deciduous trees and more improved land, and spend less for fertilizers. The difference in the amount of improved land is less now than it was in 1880, however, for the increasing consumption of fertilizers tends to obliterate original differences in soil fertility.



A SOIL SAMPLER FOR BACTERIOLOGICAL AND CHEMICAL PURPOSES

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Samples of soil for bacteriological examination are generally obtained by digging a trench with a spade, sections being then taken with a sterilized spatula from the vertical wall at the end of the trench. This involves a considerable amount of labor and inconvenience, especially when sub-surface portions are desired. Furthermore, on plots planted to crops, the trench method disturbs the soil mass in an objectionable way, particularly when samples are taken at frequent intervals. Thus when composite samples are obtained to ensure a more uniform sampling and when these are taken six or twelve times a year, a method causing much digging over of the soil is not feasible.

For chemical and physical studies soil augers may often be used, the procedure being to enlarge and clean the boring with the larger auger and sample with the smaller. But this method is not satisfactory for bacteriological studies as there is always more or less contamination of the lower sections by the soil from the surface falling down into the boring. Moreover, it is impossible to remove the soil from the auger without exposing and contaminating it. Bacteriological samples may be conveniently obtained from the surface layer only, using the apparatus described by Noyes in the *Journal of the American Society of Agronomy* (vol. 7, no. 5, p. 221).

THE SAMPLER

In order to obtain samples below the surface the author devised a sampler, the five parts of which are illustrated by longitudinal drawings in figure 1. *C* shows the surface shield, the upper flange, *a*, being 10 inches in diameter and $\frac{1}{8}$ inch thick while the tube *b*, is 4 inches long and has an inside diameter of $2\frac{1}{4}$ inches.

The sampling tube, *A*, is $3\frac{1}{2}$ feet long and has an inside diameter of $1\frac{1}{4}$ inches. It is divided into two parts, *a* and *b*. Piece *a* (shown by *B*) is 11 inches long and has a point made so that the core slides easily up through the tube. The inner shoulder above the cutting edge is about $\frac{1}{8}$ inch wide. Piece *a* is attached to piece *b* by means of a bayonet, or groove and key joint, made so that it closes and tightens when the upper part of the tube is turned to the right. A slight twist to the left enables one to detach the lower

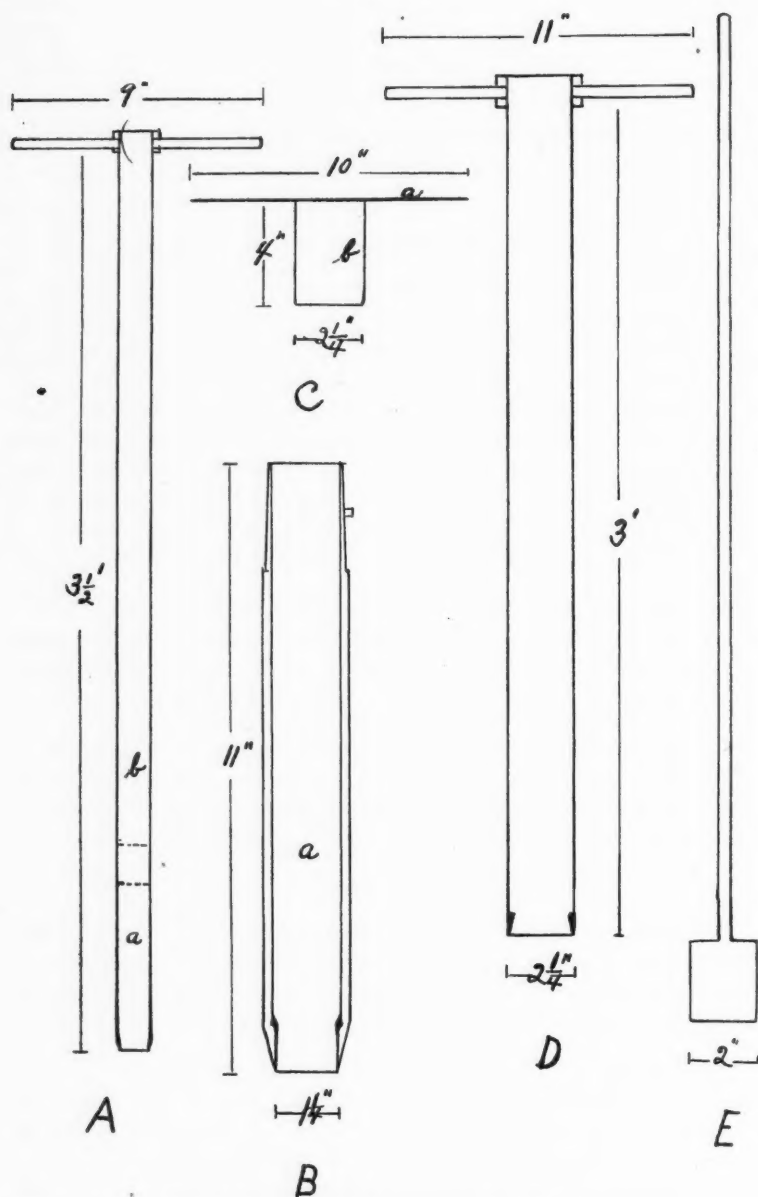


FIG. 1. LONGITUDINAL SECTIONS OF SOIL SAMPLER.

A, The sampling tube; B, lower end of the sampling tube of A; C, the surface shield; D, the cleaning and enlarging tube; E, tamper to be used with cleaning tube when necessary.

piece and remove the core of soil. The shoulders of this joint taper slightly into each other so as to come together and take up any looseness resulting from wear.

Instead of the bayonet joint an ordinary pipe coupling union may be used, although it is not as handy or as easy to separate and to unite the two parts of the tube when this device is employed.

The cleaning tube, *D*, has an outside diameter that permits it to slip easily but snugly through the surface shield, *C*. Otherwise, the construction is similar to that of the sampling tube except that the point does not taper in to obtain the cutting edge. This should be avoided in order that particles of soil may not work up between the cleaning tube and the surface shield in the process of sampling. Each of the tubes is reinforced at the top with a flange $\frac{3}{16}$ inch thick and the handles are screwed through the flange and the wall of the tube. The tubes may be laid off into the desired divisions, for instance every 6 inches, by cutting shallow grooves in them with a lathe.

In loose dry soil it is advisable to use the tamper, *E*, to tamp down the soil in the cleaning tube before removing it from the boring, thus making sure that the bottom of the boring is well cleaned and that no soil drops back into it. In moist soils this precaution is hardly necessary.

The material used throughout consists of a good grade of tool steel, with the exception of wooden handles on the larger tube and the cylindrical wooden plunger of the tamper.

METHOD OF SAMPLING

To use the sampler the surface shield is first thrust into the ground. This prevents any of the loose surface soil from falling into the boring as it is made. The first or surface section is then taken with the sampling tube (plate I, fig. 1). Only the small lower piece *a* (fig. 1, *A*) needs to be sterile. It may be plugged with cotton and sterilized in a hot-air oven before taking it from the laboratory. For sterilization in the field alcohol is used. Contamination from above is prevented by inserting a cotton plug into the bottom of piece *b* (fig. 1, *B*) and then flaming it. When a core of the desired length is in the sampler, piece *a* is removed by a slight turn to the left and the core is allowed to slide out through the upper end into a sterile glass jar. In case one does not desire to disturb the core, the tube may be capped and similar tubes, previously sterilized, used for the other sections. To obtain the next section below the surface the cleaning tube is inserted, to clean and enlarge the boring down to the desired depth, using the tamper (fig. 1, *E*) to compact this core in case it is too loose to remove completely without tamping. The sampling tube is then lowered into the enlarged boring, care being taken that its point does not touch the side walls. In this manner the desired number of sub-surface samples may be obtained. If composite samples are desired additional borings may be made over a given area, sections from a given depth being added to the jar marked to receive them.

In sampling for chemical analysis the procedure is similar except that the apparatus need not be sterilized.

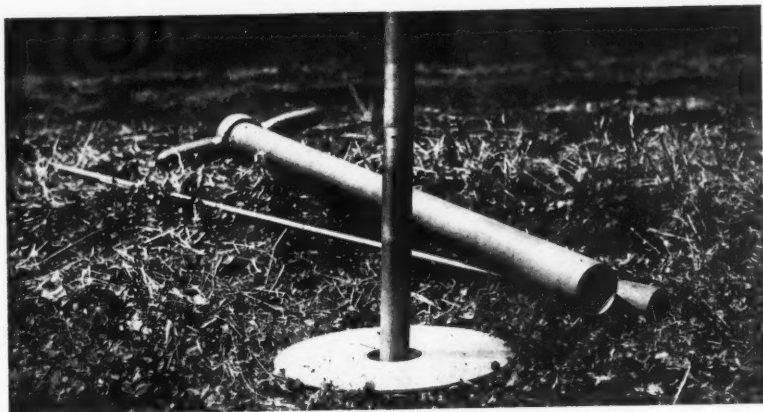
The sampler fits together conveniently and may be carried by means of a strap (plate I, fig. 2). Its total weight is about 12 pounds. A mechanic of ordinary ability should have no trouble in making one. It is giving satisfactory service in bacteriological investigations which are being conducted at the New Jersey Agricultural Experiment Station.

An expression of appreciation is extended to Dr. J. G. Lipman and Prof. A. W. Blair for their kindly interest and constructive criticism.

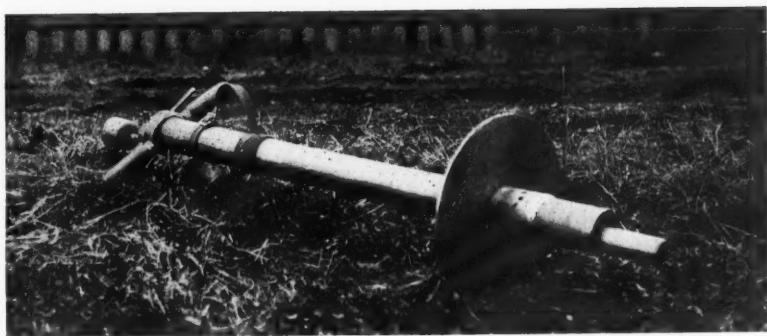
PLATE I

FIG. 1. Apparatus in position for taking the surface section. The arrow points to the joint in the sampling tube.

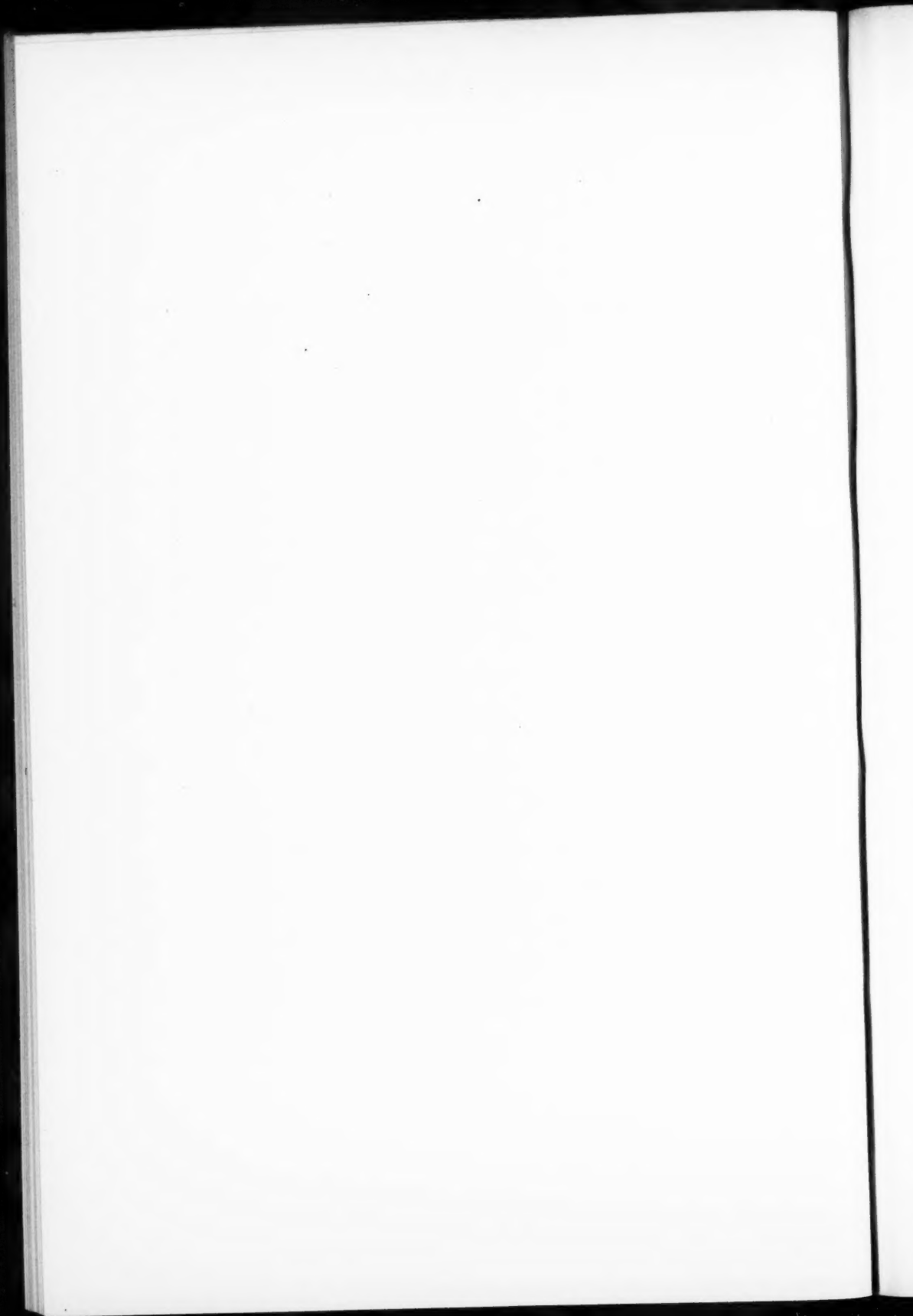
FIG. 2. Showing the relative size of the tubes.



1



2



EXPERIMENTS IN METHODS FOR DETERMINING THE REACTION OF SOILS

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INTRODUCTION

In former papers (6, 7, 9, 10), the author has published results obtained from extensive investigations in determining the influence the reaction and basicity of the soil exerts upon its condition. He was able to state that this influence is very complicated and many-sided. He demonstrated that by determining the above-named characteristics of the soil, comparatively certain information as to the need for lime in the soil might be obtained. This is of especial interest for practical purposes.

The methods used in the investigations mentioned above were largely qualitative. Despite this fact they have given reliable information as to the need for lime in the soil. The author, as indicated (9, p. 382), thinks that this is due to the fact that the need for lime in soil is not (as in the case of need for nitrogen, phosphoric acid or potassium), first of all determined by the amount of nutritive elements present in the soil in a form available for plants, but expresses a particular condition of the soil,—that is, *the presence or absence of certain basic substances*.

The nature of the question is such, that methods for an accurate quantitative determination of the above-named characteristics of soils might in many instances give much interesting information. For the present we will limit ourselves to investigations of the need for lime. We find that by using the qualitative methods (acid, litmus and *Azotobacter* tests), known at present, we can determine whether or not the soil contains the necessary basic substances, but we can obtain only faint suggestions as to the degree of this need, and the supply of these substances.

We must be careful not to overexaggerate the practical importance which a quantitative determination of the acidity or basicity of the soil might have in indicating its lime-requirement. We must remember that by treating lime-poor soils with chalk or marl, an attempt is made to give a surplus of lime sufficient for a number of years—in other words, a surplus of basic substances; and that the more complete and expensive the experimental methods, the less the possibility for using them in practical work. Yet the information obtained by using such quantitative methods will doubtless give far greater

insight into the complicated relationship between soil and lime, and will be of very special importance in research work on the influence exerted by lime, applied in varying amounts, upon the condition and productivity of various soils.

I need merely mention the importance of the qualitative determination method in special research work on the influence of the acidity or alkalinity of the soil on its physical, chemical and biological conditions.

During the past year the author has investigated one phase of the above-mentioned problem, i.e., determining quantitatively the acidity of the soil; and the results of the investigations brought to a temporary close are now submitted in the first main division of this paper.

In the second main division is a series of comparative investigations of methods for making a qualitative determination of the reaction of the soil, and in connection with these some quantitative determinations of the ability of the soil to free acids from various salts.

Probably at some future time (and perhaps starting from other principles), I may have an opportunity for a renewed study of the entire complicated problem of the determination of the reaction of soils. The results here presented are but a modest contribution toward the solution of that problem.

I. QUANTITATIVE DETERMINATION OF THE REACTION OF THE SOIL

1. Methods for making a quantitative determination of the acidity of the soil

The method hitherto used in the majority of cases for determining the degree of acidity in the soil, is the one recommended by B. Tacke (29), leader of the Moor-Experiment Station in Bremen. The method is particularly adapted to the investigation of humus-soils.

The principle underlying the method is to determine the amount of CO_2 which a certain quantity of soil mixed with a surplus of calcium carbonate is able to free from this salt.

As Tacke himself indicates, this method does not give absolutely constant or accurate results. The carbonic acid never wholly ceases to generate from the humus mixed with carbonates, a condition believed to be occasioned by "inner reactions" of humus stuffs taking place during the treatment. In order to strengthen this weakness in the method Tacke's collaborator, H. Süchting (26, 27), has modified the method so that instead of making a direct determination of the carbonic acid freed by the action of soil acids on carbonates, a determination is made of the amount of carbonates left in the retort after reaction has taken place. A surplus of hydrochloric acid is added to this remainder and the amount of carbonic acid generated is determined in the usual way. The difference between the amount of carbonic acid added, and the amount of carbonic acid remaining in combination, gives us an expression for the acid content of the soil.

Süchting shows that this modification of Tacke's method gives greater surety and accuracy than the original method, for the "inner reactions" of humus stuffs referred to above are here present in but very limited amounts. In both methods the reaction takes place at ordinary room-temperature.

In 1903, three Americans, Hopkins, Knox, and Pettit (17), published a method for determining the acidity of soils based upon the ability which acid soils inter-reacting upon neutral salts have to free acids from them. In 1905 the American agricultural chemists convened in Washington adopted this method as the one to be used for the present when determining the acidity of the soil. The method proposed is as follows.

One hundred grams of soil are placed in a 400 cc. retort and covered with so much of a 5 per cent sodium chloride solution, that it, together with the water contained in the soil, yields 250 cc. of liquid. The retort is placed in an agitator and shaken for three hours (or shaken by hand every half-hour during a period of twelve hours). The mixture is filtered and the acid content of 125 cc. of the filtrate determined by titration with diluted NaOH, using phenolphthalein as an indicator.

If for the 125 cc. of liquid taken from the retort an equal amount of a fresh sodium chloride solution is substituted and the above process followed, we find, according to investigations made by Hopkins and his collaborators that the next 125 cc. of liquid titrated contains about two-thirds as much acid as the first portion, and that portion no. 3, contains two-thirds as much as portion no. 2, etc. From this constancy we are able to compute the factor with which the result of the first three titrations may be multiplied in order to express the absolute acidity. This factor is estimated to be about 3.¹

Based on the determinations made according to this method, and the determinations as to the weight of soil per cubic measure, it is possible to estimate how large an amount of lime will be necessary for neutralizing an acre of soil to a certain depth, and the above-mentioned scientists take for granted that this amount expresses the lime-requirements of the soil.

As Baumann and Gully (4) have later proved, the ability of the soil to free acid from salts of so strong an acid as hydrochloric acid is very limited, and these scientists therefore emphasize the fact that when it is a question of an approximately absolute determination of the ability of the soil to absorb bases, it is preferable to use salts of weak acids. Veitch (32) has pointed out that the deduction made by Hopkins and his collaborators that a combination of sodium chloride solution with acid soil frees hydrochloric acid is incorrect, and that the acid reaction of the liquid is due to the formation of aluminum chloride.

A similar method has been proposed very recently by the Japanese scientist G. Daikuhara (12) who, however, instead of using sodium chloride solution, used a 1/1 N solution of potassium chloride, for he points out the fact that the soil is able to absorb a far greater amount of potassium than of

¹ Later Hopkins (17), as a result of continued experiments, prefers to use factor 4.

sodium. Using this solution the approximately absolute acidity of the soil may be computed by multiplying the first result of titration (see above) by the factor 3.

It is especially interesting to note that Daikuhara confirms Veitch's statement, that by a reaction between acid mineral soil and a potassium chloride solution, aluminum (and in certain instances iron) compounds will become soluble and too, that *the amount of these substances corresponds very closely to the amount of alkalis used up in titration*. Daikuhara therefore concludes that the acidity of mineral soils depends upon certain aluminum and iron compounds showing an acid reaction for litmus and which are absorbed by the soil colloids. The above-mentioned compounds are insoluble in water. By treating neutral soils with aluminum or iron chlorides, and then washing them out, the soils were found to cause a strong acid reaction in a potassium chloride solution.

To prove the correctness of this method for determining the acid content of soils, Daikuhara has mixed three different acid soils with just that amount of carbonate of lime, which investigation has found necessary for neutralizing these soils. After the mixture had stood for a longer time, the acidity of the soil was again determined. The result showed that the soil specimens became just neutral upon the addition of the computed amount of carbonate of lime. Furthermore, the author has arranged experiments in tubs with various soils and various plants, and he claims he has proved that the amount of lime necessary to neutralize the acidity of the soil corresponds very closely with the amount most beneficial to the plants. A more detailed report of these experiments is promised.

By means of the litmus test, and by examining the effect of a neutral solution of potassium chloride on the soil, Daikuhara has shown, that a very great quantity of acid mineral soils are to be found in Japan and Korea.

The same year as Hopkins and his collaborators published their method, another American, Veitch (31, 32), proposed using lime-water in determining quantitatively the acidity of the soil. His method in brief is as follows.

Of the given acid soil weigh off three equally large portions. To these apply various amounts of the standard solution of lime—for instance, to the first portion 10 cc., to the second 20 cc., and to the third 30 cc. Vaporize over a water-bath, and wash the vaporization remainder with the help of 100 cc. of distilled water into a Jena retort. The mixture should stand (shaken from time to time) until the next day. Then 50 cc. of the transparent liquid over the precipitate (or of the filtrate) should be placed in a Jena beaker, a few drops of phenolphthalein solution added, and the liquid vaporized until it assumes a reddish color, or if this color does not appear, until it has a volume of 5 cc.

After having roughly determined, by this method, how much lime is necessary to neutralize the soil, a more exact determination of its acidity is made, and by varying the amount of lime-water added within narrow limits (for instance, 2 cc.) an attempt is made to determine the smallest amount of lime-

water, which, when used according to the method described above, will bring about the characteristic red color reaction for phenolphthalein.

The method is very detailed, requires much time and is therefore difficult to use when many determinations of the acidity of soils are to be made. Besides, it is not easy to determine the saturation-point with sufficient accuracy, and finally, warming the soil with an alkaline solution is a weakness in the method (see further p. 120).

Yet Veitch's method is very generally used by American soil scientists, and the acidity of the soil, or what is considered the same—the lime-requirement of the soil, is expressed by the amount of lime which a weight unit of soil may absorb, or when the results are to be used by practical agriculturists—by that amount of lime which must be applied per acre in order to neutralize the top layer of soil.

Quite similar to Veitch's method is one recently published by H. B. Hutchinson and K. MacLennan (18). Instead of calcic hydrate, a 1/50 N solution of bicarbonate of lime is used. The authors describe their method as follows.

To determine the acidity of the soil or its lime-requirement, place 10 to 20 grams of soil in a retort of 500 to 1000 cc. capacity, with 200 to 300 cc. of a *ca.* 1/50 N calcium bicarbonate solution. Remove the air in the retort by passing a carbon dioxide stream through it, thus making sure that no calcium carbonate will be precipitated during the analysis. Place the retort in an agitator and shake for three hours. Filter the liquid. Of the filtrate take an amount equal to half the amount of calcium-bicarbonate solution originally present. Titrate this with a 1/10 N acid, using methyl orange as an indicator. The difference between this result and the result obtained from titrating the liquid in its original condition, indicates the amount of lime absorbed. One cc. of 1/10 N acid corresponds to 5 mgm. of calcium carbonate.

The method² has two advantages over Veitch's method: the reaction between soil and lime occurs in an approximately neutral and un-heated solution, and the work is more easily done. We have as yet insufficient data for judging the importance of the method in determining the lime-requirement of soils, but (as I shall indicate later), we hardly dare take for granted that the ability of the soil to absorb lime determines the degree of its lime-requirement.

In 1909, R. Albert (1) in Greifswalde published the following method for making a quantitative determination of the acidity of the soil.

To soil placed in water add a definite amount of baryta-water and ammonium chloride. Drive off by boiling the ammonium freed by the action of the baryta-water on the ammonium salt, and collect in a retort with diluted sulfuric acid. A previous determination should have been made of the amount of ammonium going into the retort when pure materials are used, and the difference between this amount and the amount of ammonium freed after

² These authors, too, take for granted the quite general impression that the degree of the ability of the soil to absorb lime is at the same time a measure for the degree of its acidity and its lime-requirement.—H. R. C.

soil has been added measures the amount of baryta necessary for neutralizing the soil acids—or expresses the acidity of the soil.

Besides being much simpler and more easily carried out than the Tacke-Süchting method, this method claims the additional advantage of being able to express the measure of the basicity of the soil, for when basic soils are used, more ammonium is freed than corresponds to the amount of baryta water used.

J. A. Bizzell and T. L. Lyon (5) who also consider the determination of the power of the soil to absorb lime to be the best method for expressing quantitatively the lime-requirement of the soil, have recently attempted to better Albert's method. They heat the mixture of baryta-water and soil for an hour in a boiling water-bath before adding ammonium chloride and making the subsequent distillation. They have proved that the absorption of barium does not take place as quickly as Albert took for granted. Moreover, these scientists prove that soil heated with a pure ammonium chloride solution is able, to a certain extent, to free ammonium from this, but as the ability varies in the various soils, it is necessary in each case to correct the results obtained by distillation with baryta-water with that obtained by the named blind determination.

As Süchting and Arndt (28) have pointed out, the method used by Albert, and which at first glance appeared so attractive, is wrong in principle; for the strongly alkaline hydroxides (especially on the application of heat) decompose the organic substances in the soil. Therefore, methods based on this principle cannot be used for making an exact determination of the acidity or basicity of the soil.

In the papers appearing in the two years 1909 (2) and 1910 (4), A. Baumann and his collaborator, E. Gully, basing their opinion on results from modern colloidal chemistry as well as on their own wide researches, insist, especially in the case of sphagnum-peat, that it is incorrect to speak of acidity in general, for the acid effects of that substance (for instance its ability to color litmus paper red), should be explained as surface effects (adsorption effects). In sphagnum-peat it is not a question of acidity determination but merely of its power to adsorb bases (or what is the same thing—to free acids).³ A good expression of this power, according to Baumann and Gully, is to treat peat with a calcium acetate solution and determine the amount of acid freed by the inter-action of these substances.

As in the opinion of the above-named scientists, the freeing of acetic acid is solely due to surface effects, this for the most part, quantitatively seen,

³ As I have shown in a previous paper (9) Baumann and Gully are not entirely right. In the electro-metric measurements which the author of this present article in collaboration with J. Witt and N. Feilberg has made of hydrogen-ion concentration in mixtures of raw sphagnum peat and water, a considerable number of hydrogen-ions were found present. G. Fischer (13) attained a similar result from electro-metric determinations of hydrogen-ion concentrations in various samples of sphagnum-peat from German bogs.

will depend on the relative amounts of soil and calcium acetate solution used. An accurate expression for the absolute power to free acids will, therefore, be obtained only by varying these amounts. When, following the experiments of the above-named scientists, we use a limited amount of peat (3 gm.) with a very large amount of concentrated calcium acetate solution,⁴ we obtain an approximately correct expression for the absolute power to free acids; for under these conditions possibilities have been brought about for an approximately maximum adsorption of the base of the salt named, and the results of the acid-determinations carried out in this manner seem to coincide very closely with the results of acid-determinations made with the use of diluted sodium hydroxide.

In mineral soils, the use of solutions of acetates for acidity determinations has been proposed by Oscar Loew (20), who uses the following method.

Fifty grams of air-dry pulverized soil are placed in a 200 cc. neutral 1 per cent solution of sodium or potassium acetate. The mixture should stand (shaken, however from time to time), for 24 hours in a normal room temperature. It is then filtered and of the filtrate 100 cc. measured off for titration.

By the help of this method, Loew claims that an approximate determination of the amount of lime necessary for neutralizing the soil can be made.

Ach. Grégoire (15) and his collaborators have attempted to determine the reaction of the soil by shaking it with a mixture of solutions of potassium-iodate, potassium iodide and sodium hyposulfite, proposed by Kjeldahl in his acidimetric determinations, and titrating the iodine freed in reaction with free soil acids with a sodium hyposulfite solution, using starch-water as an indicator. By this method the authors have demonstrated that mineral soils may vary greatly in acidity. They mention the fact that silicic acid and zeolites do not affect the reagent, while, on the other hand, this is very sensitive to calcium bicarbonate. Sodium bicarbonate affects it to a very slight degree.

Stutzer and Haupt (24) have applied this principle in the quantitative determination of the reaction of the soil, and give a detailed account of the method for such a determination. In another paper (25), the above-mentioned authors draw attention to the fact that the application of the principle is limited, for iodine may also be freed by ferri-salts, cupri-salts, free chlorine, sodium hypochlorite, and—in the presence of acids—by oxidizing chemical combinations; for instance, peroxides, potassium permanganate and potassium bichromate.

⁴ In a later publication of E. Gully (16), it appears that in the experiments referred to here, as to the ability of sphagnum-peat to free acids by means of the lime-acetate method, 3 grams of air-dry peat has been used with 200 cc. of 10 per cent solution of calcium acetate, and a three-hour reaction time.

In the article in which Baumann and Gully (4) for the first time present the idea of using calcium acetate in determining the ability of sphagnum-peat to free acid, nothing is said as to whether the weight of peat used (3 grams), referred to fresh moist peat, or to dry peat.

Finally we must mention J. G. Lipmán's proposal (19). In determining the acidity of the soil he uses a micro-biological method, based on the sensitiveness of certain bacteria to the presence of free acids in the substratum.

A series of equally large portions of a neutral bouillon are measured off. In each place a different quantity of the soil sample under examination (for instance, 0.5 gram, 1 gram, 3 grams, 5 grams, 10 grams). Sterilize all the bouillon portions, and when cool infect with the standard bacterium chosen (*Bacillus mycoides* or *Bacillus subtilis*). After a certain length of time has elapsed, determine the degree of bacteria development in the bouillon culture by measuring the amount of ammonium found. If, for the sake of comparison, similar experiments are made with bouillon portions minus soil, in which the degree of acidity varies, due to the direct addition of varying amounts of acid to each portion, it is possible—within a certain limit—to determine to what amount of acid the development of a definite amount of ammonium by a definite quantity of soil corresponds.

According to Lipman's observations, the above-mentioned species of bacteria can develop in an acid content of up to 2 per cent of the weight of the bouillon. In these experiments it is possible also to use *Azotobacter* with a mannite solution for their nourishment.

Lipman promises further accounts of experiments based on this principle, and not until these appear can we form a positive estimate of the value of this method for determining the acidity of the soil. However, since in addition to the acidity various other soil characteristics exert a great influence on the development of bacteria, and on the decomposition of the nourishment substrata already mentioned [see further Harald R. Christensen (9)], it would appear in advance that this method is not exact enough. Even could all such difficulties be eliminated, the results obtained—especially from the bouillon-culture—seem rather to express the hydrogen-ion concentration in the substratum than the absolute quantity of acid, for it appears to be the latter alone which determines the extent of the enzymatic decompositions [see further S. P. L. Sørensen (23)]. The necessity for sterilizing the bouillon portions after the soil has been added is a weakness in the method, in view of the chemical changes in the soil caused by heat.

Without at this point going further into the discussion of the much disputed question of the existence of humus acids, the author wishes to express as his opinion, that in view of the results obtained from the chemical experimental methods described above, it is more correct to speak of *acid-freeing power* or *base-adsorption power* of the soil, than of the *acidity* of the soil. To determine this last-mentioned power, it will probably be necessary to use other principles, than those in general use at the present time. Possibly experiments with hydrogen-ion concentration will give valuable information in this connection, even though in agricultural soil analyses such determinations could scarcely take the place of determinations of the absolute acid content of the soil.

In the investigations described below only those methods have been used which are able to express—more or less completely—the ability of the soil to free acids from salts. As the method used by Baumann and Gully (4) (the acetate method) seemed to the author to be the simplest and most attractive of the methods hitherto proposed, particular emphasis has been placed upon

a fuller test of the feasibility of adopting this method, and upon giving it such a form that it may be used under the greatly varying conditions in agricultural soil investigations.

2. The use of the calcium acetate method in determining the ability of the soil to free acids

As various soil chemists, M. Fleischer (14), Baumann and Gully (4), and others have shown, the amount of acid which a definite quantity of peat is able to free in a neutral salt solution is determined to a large extent by the relation between the amount of peat and the amount of salt solution used. In regard to the freeing of acetic acid from acetates, Baumann and Gully (4, p. 125) have made absorption experiments using a 25 per cent solution of sodium acetate with fresh sphagnum, as well as with sphagnum-peat, and shown that this ability diminishes perceptibly when the quantity of these last-named substances is increased.

My object is first and foremost to throw light upon the extent to which this relationship appears when the calcium acetate method is used with various soils.

As mentioned before page 121, the absolute value of the ability to free acids is approached the more closely, the larger the difference between the amount of peat and of acetate solution used. However, as the determination (titration) of the acid freed, may be made with the greater accuracy, the larger the amount, it is important not to make the difference too small. Closely connected with these investigations, others have been made as to the influence of the reaction-time on the freeing of acids, and finally as to the influence of air-drying on this ability.

These investigations include both humus soils and ordinary field soils (mineral soils).

The method used is as follows:

Place the soil when weighed off, in a retort of about 500 cc. capacity and cover with exactly 300 cc. of calcium acetate solution (1 gram of calcium acetate to 10 cc. of distilled water). Cork the retort and shake from time to time during the entire reaction-period. When the prescribed length of time has elapsed, filter the solution and titrate (with 1/10 N sodium hydrate) using phenolphthalein as an indicator.

In titration 50 to 100 cc. of the filtrate is used, preferably the former amount, as the change is the more distinct the smaller the amount of fluid. By titrating 3 or 4 portions from the same filtrate, and taking the average of the single titrations, even a very slightly acid content can be estimated with great accuracy. It is important not to use too much phenolphthalein as the most distinct change appears when a relatively small amount (3 to 4 drops of a 1 per cent solution) is used. Phenolphthalein causes precipitation in a calcium acetate solution, and therefore the change of color is not so distinct as when (for instance) sulfuric acid is titrated. Dropping with sodium hydrate must cease at the first suggestion of a change in color (very

slight dirty red tinge). Duplicate determinations were always made (duplicate retorts being used), besides, as was mentioned before, taking 3 to 4 titrations of the filtrates from each retort. As the watery solution of calcium acetate of commerce⁵ is neutral only by exception, and usually shows a slightly acid or alkaline reaction for phenolphthalein, a blind determination of the reaction in the solution used must be taken, and the value found either added to, or subtracted from the values obtained by titrating the filtrates from the mixture⁶ of soil and water.

The power to free acid is, in every investigation made, expressed by the amount of acid—given in the number of cc. 1/10 N acid—which 1 gram of dry soil is able to free in the calcium acetate solution used.

a. Investigations as to the influence which the relation between the amount of soil and of calcium acetate solution, as well as the reaction-time, exert on the ability of the soil to free acid. In these investigations, high-bog peat⁷ and low-bog peat⁸ from the bogs near Studsgaard and Tylstrup, silt-soil from meadows near Varde, and acid field soils have been used.

The moist peat soils were ground in an ordinary meat chopper. This treatment, which presents no difficulty, and a subsequent stirring gave the material a homogenous form and made it easy to handle. Field soils, like the peat soils, were used in their natural moist condition, the various samples thoroughly mixed and possible small pebbles thrown away before being weighed and placed in the retorts. No other special preparation was made.

In table 1, are the results of a series of investigations in which both the amount of soil and the reaction-time were varied simultaneously, while the amount of liquid (300 cc.) remained constant. The results are shown graphically in figure 1.

The investigations were made in two series.

If we turn first to the results of the investigations in Series I, we see that both the quantity of the soil and the reaction-time exert an important influence on the extent to which acid is freed.

Agreeing with the report from Baumann and Gully (4), we too find the largest amount of acid free per weight unit of soil when the smallest amount of peat soil is used. But as the table shows, by prolonging the reaction-time we possess a means for eliminating totally or partially those differences which appear when varying quantities of soil are used. Judging by the results obtained from peat soils, a five-hour reaction-time seems to yield approximately the maximum amount of acid freed, if the amount of peat used is not larger than a corresponding 0.5 gram to 0.75 gram of dry soil. When larger quantities of peat are used the values for the amount of acid freed, gen-

⁵ The calcium-acetate used in the investigations comes from Kahlbaum, Berlin.

⁶ In Baumann and Gully's investigations the solution is neutralized before being used.

⁷ Danish—Højmoesetrv; German—Hochmoortorf.

⁸ Danish—Lavmoesetrv; German—Niedermoortorf; English—fen (according to Edw. J. Russell, Soil Conditions and Plant Growth, p. 69-70).

erally seem to diminish appreciably. For field (mineral) soils, a five-hour reaction-time seems to yield approximately the maximum amount of acid freed per weight unit of soil, when an amount up to 10 to 15 grams of dry soil is used. Were the reaction-time but three hours, only 5 grams of dry soil could be used when proportionately just as large an amount of acid is to be freed.

Later, certain observations of the influence of the reaction-time on the amount of acid freed seemed to indicate that a five-hour reaction-time was not sufficient for all soils to bring the reaction between the soil and the calcium acetate solution to a close. New investigations (table 1, series 2; and

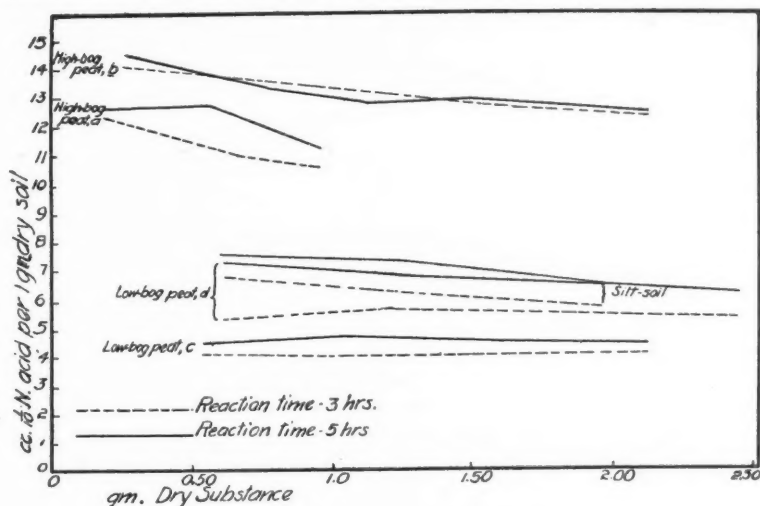


FIG. 1. DIAGRAM SHOWING THE INFLUENCE OF THE AMOUNT OF SOIL AND THE REACTION-TIME ON THE AMOUNT OF ACID FREED FROM CALCIUM ACETATE SOLUTION

table 2) were made, high-bog peat, low-bog peat, mineral soils and silt soil being used.

The results of these investigations establish the fact that the reaction-time as well as the proportional amounts of soil and salt solution used, have a great influence upon the degree of the amount of acid freed, and as may be seen from the tables, of these two factors, the reaction-time is usually the more important.⁹ In the case of high-bog peat this factor is of relatively

⁹ Though in the case of colloid material it is difficult to determine to what extent we are dealing with adsorption or with chemical reaction, it is generally safe to say that the first process ceases quite quickly. When such a heterogeneous material as soil is used, of which the larger part consists of combinations very difficult of solution, a very long time may elapse before the chemical equilibrium is established. The great influence which the reaction-time in these experiments exerts on the absorption of bases may perhaps indicate that this absorption is not occasioned by surface effects alone.

TABLE 1

The influence of the amount of soil used and the reaction time on the ability of the soil to free acids

Series 1

GRAMS SOIL USED		REACTION TIME IN HOURS	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID			
Fresh, moist	Dry*		Per 100 cc. liquid		Per 1 gm. moist soil	Per 1 gm. dry* soil
			The single retorts†	Average		
High bog peat A from "Knudemose" near Herning (strong acid reaction)						
3	0.30	3	1.26 1.23	1.25	1.25	12.5
6	0.60	3	2.26 2.31	2.29	1.15	11.5
9	0.90	3	3.21 3.31	3.26	1.09	10.9
3	0.30	5	1.28 1.26	1.27	1.27	12.7
6	0.60	5	2.55 2.47	2.51	1.27	12.7
9	0.90	5	3.50 3.45	3.48	1.16	11.6
High-bog peat B from "Store Vildmose" near Tylstrup (strong acid reaction)						
3	0.36	3	1.67 1.67	1.67	1.67	13.9
6	0.72	3	3.26 3.26	3.26	1.63	13.6
9	1.08	3	4.64 4.74	4.69	1.56	13.0
12	1.44	3	6.09 6.14	6.12	1.53	12.7
18	2.16	3	8.85 8.80	8.83	1.47	12.3
3	0.36	5	1.75 1.70	1.73	1.73	14.4
6	0.72	5	3.24 3.21	3.23	1.62	13.5

TABLE 1 (Cont.)

GRAMS SOIL USED		REACTION TIME IN HOURS	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID			
			Per 100 cc. liquid		Per 1 gm. moist soil	Per 1 gm. dry* soil
			The single retorts†	Average		
Fresh, moist	Dry*					
High-bog peat B from "Store Vildmose" near Tylstrup (strong acid reaction)						
9	1.08	5	4.63 4.61	4.62	1.54	12.8
12	1.44	5	6.17 6.14	6.16	1.54	12.8
18	2.16	5	8.91 8.99	8.95	1.49	12.4
Low-bog peat A from "Store Vildmose" (strong acid reaction)						
1½	0.26	3	0.71 0.71	0.71	1.42	8.2
3	0.52	3	1.41 1.44	1.43	1.43	8.3
4½	0.78	3	2.13 2.13	2.13	1.40	8.1
6	1.04	3	2.94 2.85	2.90	1.45	8.4
1½	0.26	5	0.71 0.71	0.71	1.42	8.2
3	0.52	5	1.31 1.41	1.36	1.36	7.9
4½	0.78	5	2.09 2.07	2.08	1.39	8.0
6	1.04	5	2.91 2.84	2.87	1.44	8.3
Low-bog peat B from "Tylstrup" (strong acid reaction)						
3	0.57	3	1.70 1.65	1.68	1.68	8.8
6	1.14	3	3.23 3.26	3.25	1.63	8.6

TABLE 1 (Cont.)

GRAMS SOIL USED		REACTION TIME IN HOURS	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID			
			Per 100 cc. liquid		Per 1 gm. moist soil	Per 1 gm. dry* soil
			The single retorts†	Average		
Fresh, moist	Dry*					
Low-bog peat B from "Tylstrup" (strong acid reaction)						
9	1.71	3	4.36 4.36	4.36	1.45	7.6
12	2.28	3	5.62 5.67	5.65	1.41	7.4
18	3.48	3	7.69 7.82	7.76	1.29	6.8
24	4.56	3	9.72	9.72	1.22	6.4
Good sandy soil (acid reaction)						
3	2.6	3	0.65 0.65	0.65	0.65	0.75
6	5.2	3	1.21 1.21	1.21	0.61	0.70
9	7.8	3	1.80 1.90	1.85	0.62	0.72
12	10.4	3	2.22 2.17	2.20	0.55	0.63
15	13.0	½	2.41 2.36	2.39	0.48	0.55
15	13.0	3	2.71 2.71	2.71	0.54	0.63
15	13.0	5	2.86 2.81	2.84	0.57	0.66
Clay soil (A) (acid reaction)						
3	2.5	3	0.55 0.60	0.58	0.58	0.70
6	5.0	3	0.98 1.03	1.01	0.51	0.60

TABLE 1 (Cont.)

GRAMS SOIL USED		REACTION TIME IN HOURS	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID			
			Per 100 cc. liquid		Per 1 gm. moist soil	Per 1 gm. dry* soil
Fresh, moist	Dry*		The single retorts†	Average		
Clay soil (A) (acid reaction)						
9	7.5	3	1.26 1.40	1.33	0.44	0.53
12	10.0	3	1.70 1.85	1.78	0.45	0.53
18	15.0	3	2.34	2.34	0.39	0.47
3	2.5	5	0.53 0.53	0.53	0.53	0.64
6	5.0	5	1.00 1.02	1.01	0.51	0.60
9	7.5	5	1.56 1.51	1.54	0.51	0.62
12	10.0	5	2.11 2.05	2.08	0.52	0.62
18	15.0	5	2.91 2.91	2.91	0.49	0.58
Series 2						
High-bog peat C from "Knudemose" (strong acid reaction)						
6	0.88	3	2.95 3.11	3.03	1.52	10.3
3	0.44	5	1.73 1.69	1.71	1.71	11.6
6	0.88	5	3.21 3.19	3.20	1.60	10.9
12	1.76	5	6.06 5.86	5.96	1.49	10.2
Low-bog peat C from Gelleruplund (acid reaction); (6/10 1913)						
2	0.542	3	0.73 0.70	0.72	1.08	4.0

TABLE 1 (Cont.)

GRAMS SOIL USED		REACTION TIME IN HOURS	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID			
			Per 100 cc. liquid		Per 1 gm. moist soil	Per 1 gm. dry* soil
Fresh, moist	Dry*		The single retorts†	Average		
Low-bog peat C from Gelleruplund (acid reaction) (6/10 1913)						
4	1.084	3	1.44 1.40	1.42	1.07	3.9
6	1.626	3	2.15 2.19	2.17	1.09	4.0
8	2.168	3	2.90 2.90	2.90	1.09	4.0
12	3.252	3	4.26 4.24	4.25	1.06	3.9
2	0.542	5	0.77 0.81	0.79	1.19	4.4
4	1.084	5	1.72 1.78	1.75	1.31	4.9
6	1.626	5	2.52 2.54	2.53	1.27	4.7
8	2.168	5	3.41 3.41	3.41	1.28	4.7
12	3.252	5	4.93 4.91	4.92	1.23	4.5
Same low-bog peat (8/10 1913)						
2	0.542	3	0.72 0.72	0.72	1.08	4.0
4	1.084	3	1.56 1.64	1.60	1.20	4.4
8	2.168	3	3.04 3.12	3.08	1.16	4.2
2	0.542	5	0.85 0.84	0.85	1.28	4.7
4	1.084	5	1.76 1.72	1.74	1.31	4.8

TABLE 1 (Cont.)

GRAMS SOIL USED		REACTION TIME IN HOURS	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID			
			Per 100 cc. liquid		Per 1 gm. moist soil	Per 1 gm. dry ¹ soil
			The single retorts†	Average		
Fresh, moist	Dry*					
Same low-bog peat (8/10 1913)						
8	2.168	5	3.45 3.41	3.43	1.29	4.7
12	3.252	5	5.08 5.02	5.05	1.29	4.7
2	0.542	7	0.95 0.91	0.93	1.40	5.1
4	1.084	7	1.97 1.89	1.93	1.45	5.3
8	2.168	7	3.72 3.82	3.77	1.41	5.2
Low-bog peat D from "Store Vildmose" (strong acid reaction)						
2.1	0.612	3½†	1.15		1.64	5.6
4.2	1.224	3	2.35		1.68	5.8
8.4	2.448	3	4.40 4.48	4.44	1.59	5.5
16.8	4.896	3	8.59 8.41	8.50	1.52	5.2
2.1	0.612	5	1.47		2.1	7.2
4.2	1.224	3	2.68 2.82	2.75	1.96	6.7
8.4	2.448	3	5.15 5.15	5.15	1.84	6.3
16.8	4.896	3	9.21 9.19	9.20	1.64	5.6

TABLE 1 (Cont.)

GRAMS SOIL USED		REACTION TIME IN HOURS	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID			
			Per 100 cc. liquid		Per 1 gm. moist soil	Per 1 gm. dry* soil
Fresh, moist	Dry*		The single retorts†	Average		
Silt soil no. 12 (acid reaction)						
3	0.62	3	1.39 1.43	1.41	1.41	6.8
6	1.24	3	2.57 2.63	2.60	1.30	6.3
9	1.86	3	3.67 3.67	3.67	1.22	5.9
3	0.62	5	1.58 1.54	1.56	1.56	7.5
6	1.24	5	2.90 2.92	2.91	1.46	7.1
9	1.86	5	3.98 4.02	4.00	1.33	6.5
Loam soil, poor in humus (B) (strong acid reaction)						
5	4.6	3	0.66 0.72	0.69	0.41	0.45
10	9.2	3	1.23 1.25	1.24	0.37	0.40
20	18.4	3	2.09 2.09	2.09	0.31	0.34
10	9.2	5	1.29 1.29	1.29	0.39	0.42
5	4.6	7	0.78 0.76	0.77	0.46	0.50
10	9.2	7	1.34 1.30	1.32	0.40	0.43
20	18.4	7	2.29 2.29	2.29	0.34	0.37

* Here, and in the following investigations, "dry" applied to peat soils means "oven-dry," applied to field soils, "air-dry."

† Here and later, after correction has been made for content of water in the soil.

‡ Due to an oversight the reaction-time was 20 minutes too long.

• small importance, even though when larger quantities of peat are used, there is a distinct difference between a three and a five-hour reaction-time; in high-bog peat, specimens A and C, increasing the reaction-time has annulled the difference in amounts of acid freed, caused by using various quantities of soil. In high-bog peat, specimen B, the amount of acid freed is just as large after a three-hour as after a five-hour reaction-time, and this experiment merely expresses the variations caused by the differences in the amount of peat used. However, these variations are comparatively small, not only here but also in other specimens of high-bog peat examined.

Low-bog peat C is a clear example of a type of soil in which the relation between the amounts of soil and of calcium acetate solution has no influence on the amount of acid freed, which, on the other hand, is largely determined by the length of the reaction-time. As appears in table 1 (series 2) the various amounts of peat (from 0.54 gram to 3.25 grams of dry peat soil) used have freed an equally large amount of acid per weight unit during the various reaction-times. The same experiment also proves that even a reaction-time of five hours was insufficient to complete the base-absorption, for during an additional two hours a very appreciable increase in the amount of acid freed was observed. (A further discussion of this will follow later.)

In low-bog peat D it was apparent that in a three-hour reaction-time approximately the same amount of acid was freed per weight unit of peat, even though the amount of peat used varied between 0.61 gram to 4.9 grams of dry soil. If the reaction-time was increased to five hours in all the samples of peat examined, the amount of acid freed was likewise found to increase, but the amount varied greatly in the various samples. This specimen of low-bog peat acts otherwise than specimen A from the same bog and which freed the same amount of acid even when the reaction-time was increased (over three hours), and the amount of peat varied.

In the case of silt soil no. 12, and the two loam soils, both the amount of soil used and the reaction-time have influenced the extent of acid freed.

In loam soil A an increase in the reaction-time from three to five hours was sufficient to almost entirely eliminate the difference in amount of acid freed caused by using various amounts of soil. This was not true in loam soil B, for after a period of seven hours the difference was still very apparent. On account of the limited power of this soil to free acid, the differences in amount of acid freed during the reaction-times tested and with the smaller quantities of soil used are so small that the titration method in use is powerless to determine them exactly. Yet the absolutely as well as relatively appreciable difference in acid freed per weight unit of soil between the largest amount of soil (20 grams), and the smallest amount (5 grams) used, indicates positively that in this type of soil, in contrast with loam soil A, the amount of acid freed is more largely determined by the amount of soil used than by the length of the reaction-time.

In order to illustrate further the extent to which the freeing of acid is de-

terminated by the reaction-time, the experiments referred to in table 2 were made, and using the same quantity of soil the reaction-time was varied within very wide limits. In some of the experiments the same soil was used as in the experiment just referred to (table 1).

If in series 1, table 2, we examine the relation between humus soils and their reaction time, we see that in high-bog peat acid is freed much more quickly than in low-bog peat. When one-eighth of an hour has passed the acid freed from high-bog peat has attained 70 per cent of the total amount of acid freed during the ten-hour reaction-time; whereas low-bog peat from Tylstrup and low-bog peat from Gelleruplund yield in the same time 32 and 29 per cent, respectively.

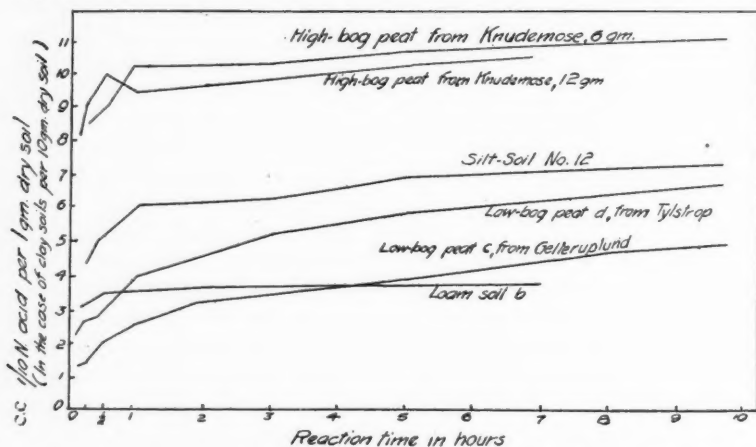


FIG. 2. DIAGRAM SHOWING THE INFLUENCE OF THE REACTION-TIME ON THE ABILITY OF VARIOUS SOILS TO FREE ACID FROM A CALCIUM ACETATE SOLUTION

Base-absorption by low-bog peat is particularly slow and is only approximately brought to an end after eight hours. In high-bog peat, silt soil and loam soil the reaction is approximately ended after five hours have passed.

It is especially interesting to note that base-absorption by high-bog peat B is quite independent of the quantity of peat used, for relatively speaking, almost the same amount is absorbed whether 12 grams of peat are used or 6 grams. The specimen of high-bog peat under discussion, belongs, therefore, to that type of soil in which the relation between the amount of soil and the salt solution is of subordinate importance in the amount of acid freed, and differs from high-bog specimen A previously examined and coming from the same bog (see table 1). In the latter case the amount of peat used exerted not a great, but yet a very distinct influence on the degree of acid freed.

In figure 2 is a diagram showing the relation between the reaction-time and the base-absorption in the various soils examined.

TABLE 2

Influence of the reaction-time on the ability of the soil to free acid, the amount of soil used being constant

Series 1

REACTION-TIME IN HOURS	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID				
	Per 100 cc. liquid			Per 1 gram moist soil	Per 1 gram dry soil
	Retort a	Retort b	Average		
High-bog peat B from "Knudemose" (strong acid reaction); 6 grams fresh, moist peat soil (0.88 gram dry soil) used in each retort					
$\frac{1}{8}$	2.29	2.22	2.26	1.13	7.71
$\frac{1}{4}$	2.64	2.41	2.53	1.27	8.63
$\frac{1}{2}$	2.53	2.66	2.65	1.33	9.04
1	2.93	3.03	2.98	1.49	10.17
2	3.09	2.64	(2.92)*	(1.46)*	(9.97)*
3	2.95	3.11	3.03	1.52	10.34
5	3.21	3.19	3.20	1.60	10.92
7	3.27	3.18	3.23	1.62	11.02
10	3.25	3.29	3.27	1.64	11.16
Same high-bog peat; 12 grams fresh moist peat soil (1.76 grams dry soil) used in each retort					
$\frac{1}{8}$	4.72	4.89	4.81	1.20	8.19
$\frac{1}{4}$	5.18	(3.43)†		1.30	8.82
$\frac{1}{2}$	5.97	5.68	5.83	1.46	9.93
1	5.70	5.30	5.50	1.38	9.37
2	5.89	5.49	5.69	1.42	9.69
3	5.91	5.79	5.85	1.46	9.97
5	6.20	6.26	6.23	1.56	10.61
7	6.41	6.35	6.38	1.60	10.87
Low-bog peat D from Tylstrup (strong acid reaction); 8.14 grams fresh, moist peat (2.447 grams dry soil) used in each retort					
$\frac{1}{8}$	1.85			0.66	2.27
$\frac{1}{4}$	2.28	2.26	2.27	0.81	2.78
$\frac{1}{2}$	2.38	2.34	2.36	0.84	2.89
1	3.41	3.20	3.31	1.18	4.06
3	4.39	4.47	4.43	1.58	5.43
5	5.15	5.15	5.15	1.82	6.31
7	5.40	5.48	5.44	1.94	6.66
10	5.68	5.74	5.71	2.04	7.00
Low-bog peat C from Gelleruplund (acid reaction); 9 grams fresh, moist peat (2.439 grams dry soil) used in each retort					
$\frac{1}{8}$	1.32	1.15	1.24	0.41	1.53
$\frac{1}{4}$	1.34	1.40	1.37	0.46	1.69
$\frac{1}{2}$	1.79	1.85	1.82	0.61	2.24
1	2.33	2.27	2.30	0.77	2.83

TABLE 2 (Cont.)

REACTION-TIME IN HOURS	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID				
	Per 100 cc. liquid			Per 1 gram moist soil	Per 1 gram dry soil
	Retort a	Retort b	Average		
Low-bog peat C from Gelleruplund (acid reaction) 9 grams fresh, moist peat (2.439 grams dry soil) used in each retort					
2	2.76	2.82	2.79	0.93	3.43
4	3.41	3.42	3.42	1.14	4.19
6	3.75	3.75	3.75	1.25	4.61
8	4.10	4.06	4.08	1.36	5.02
10	4.20	4.18	4.19	1.40	5.15
11	4.28			1.43	5.26
Silt soil no. 12 (acid reaction); 6 grams fresh moist soil (1.24 gram dry soil) used in each retort					
$\frac{1}{4}$	1.92	1.78	1.85	0.93	4.48
$\frac{1}{2}$	2.02	2.30	2.16	1.08	5.21
1	2.41	2.45	2.43	1.22	5.88
3	2.57	2.63	2.60	1.30	6.30
5	2.90	2.92	2.91	1.46	7.05
7	2.94	2.94	2.94	1.47	7.12
10	2.98	3.08	3.03	1.52	7.34
Loam soil B (strong acid reaction); 10 grams fresh moist soil (=9.2 grams air-dry soil) used in each retort					
$\frac{1}{8}$	0.94	0.96	0.95		0.31
$\frac{1}{4}$	0.98	1.06	1.02		0.33
$\frac{1}{2}$	1.10	1.14	1.12		0.37
1	1.18	1.16	1.17		0.38
2	1.20	1.26	1.23		0.40
3	1.24	1.26	1.25		0.41
5	1.30	1.30	1.30		0.42
7	1.36	1.32	1.34		0.44
High-bog peat from "Knudemose" (strong acid reaction); 7.6 grams fresh moist peat (= 1 gram dry soil) used in each retort					
Shaken from time to time (usual meth- od of pro- cedure)					
3	3.35	3.29	3.32		9.96
5	3.37	3.39	3.38		10.14
10	3.43	3.45	3.44		10.32
20	3.48	3.52	3.50		10.50

TABLE 2 (Cont.)

REACTION-TIME IN HOURS	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID				
	Per 100 cc. liquid			Per 1 gram moist soil	Per 1 gram dry soil
	Retort a	Retort b	Average		
High-bog peat from "Knudemose" (strong acid reaction) 7.6 grams fresh moist peat (= 1 gram dry soil) used in each retort					
Unshaken					
3	3.28	3.27	3.28		9.84
5	3.33	3.37	3.35		10.05
10	3.41	3.39	3.40		10.20
20	3.52	3.46	3.49		10.47
Low-bog peat from Gelleruplund (reaction undetermined); 6 grams fresh moist peat (= 1.5 gram dry soil) used in each retort					
Shaken from time to time					
3	2.31	2.37	2.34		4.68
5	2.57	2.59	2.58		5.16
10	3.12	3.12	3.12		6.24
20	3.18	3.06	3.12		6.24
19‡	3.10	3.16	3.13		6.26
Unshaken					
3	2.22	2.12	2.17		4.34
5	2.47	2.45	2.46		4.92
10	2.80	2.88	2.84		5.68
20§	3.06	3.08	3.07		6.14
19‡	3.00	2.96	2.98		5.96
Clay soil, poor in humus (acid reaction); 11.55 grams fresh moist soil (= 10 grams air-dry soil) used in each retort					
Shaken from time to time					
3	1.27	1.31	1.29		0.387
5	1.39	1.37	1.38		0.414
10	1.55	1.51	1.53		0.459
19	1.51	1.53	1.52		0.456
Unshaken					
3	1.14	1.04	1.09		0.327
5	1.20	1.20	1.20		0.360
10	1.27	1.27	1.27		0.381
19	1.47	1.47	1.47		0.441

* On account of a very considerable difference in the results of the duplicate determinations, presumably due to a flagrant error, the correctness of the average is to be disputed.

† The cause of this low—and presumably incorrect—figure is unknown. No account has, therefore, been made of this figure in computing the results per weight measure.

‡ Set aside a few days later.

§ After standing quietly for about 19 hours, the retorts were inadvertently shaken a single time.

In the last section of table 2 are the results of an examination of three different kinds of soils (high-bog peat, low-bog peat, and loam soil), in which the reaction-time varies from three to twenty hours. At the same time the importance of shaking the retorts during the reaction-time has been tested. In the first part of the experiment the retorts were shaken hard quite often¹⁰—about every fifteen minutes; in the second part of the experiment the soil and the liquid were thoroughly shaken together immediately after being placed in the retorts, and again just before being filtered; in the interim the retorts stood quietly on a shelf.

In agreement with the tests referred to in the first section of table 1, we find that the reaction between soil and calcium acetate solution ceases after a

TABLE 3

Investigations of the influence exerted by various amounts of calcium acetate solution on the ability of a certain amount of soil to free acid (reaction-time five hours)

AMOUNT OF SOIL; GRAMS OF DRY SUBSTANCE	AMOUNT OF CALCIUM ACE- TATE SOLUTION IN CUBIC CENTIMETERS	ACID FREED EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID				
		Per 100 cc. liquid			Per 1 gram of dry soil	
		Retort a	Retort b	Average		
<i>High-bog peat</i>						
1	200	4.99	4.95	4.97		9.94
1	300	3.37	3.39	3.38		10.14
1	400	2.58	2.58	2.58		10.32
<i>Low-bog peat</i>						
1½	200	3.73	3.67	3.70		4.93
1½	300	2.57	2.59	2.58		5.16
1½	400	2.03	1.99	2.01		5.36
1½	500	1.64				5.47
<i>Loam soil</i>						
10	200	1.95	1.91	1.93		0.386
10	300	1.39	1.37	1.38		0.414
10	400	1.12	1.12	1.12		0.448

period of about ten hours. Shaking the retorts has had no especial influence on high-bog peat. In the case of low-bog peat, this action has caused an appreciable increase in the amount of acid freed in the reaction-times three, five and ten hours, but in the longest reaction-time (twenty hours), the difference has almost entirely disappeared.

Table 3 shows the results of an absorption-experiment in which the amount of soil is kept constant, while the amount of calcium-acetate solution is varied. In this test the same soils are used as in the one last mentioned.

¹⁰ In the case of the longest reaction-time the retorts were shaken only during the first four to five hours and the last four to five hours before filtering. In the intervening interval they remained undisturbed.

We find that the greatest amount of acid is freed per weight unit of soil when the greatest amount of solution is used. The results agree, as was also to be expected, with those obtained from the tests previously mentioned, in which quantities of soil of varying weight were used with the same amount of calcium-acetate solution.

In order to judge the results, we will express the amount of acid freed in relation to that value found when 400 cc. of the solution is used. Expressed thus, the difference between the acid freed in 200 cc. of the solution and in 400 cc. of the solution is, for high-bog peat 3.7 per cent, for low-bog peat 8 per cent, and for loam soil 13.8 per cent. The difference in amount of acid freed when 300 cc. and 400 cc. are used is 1.7 per cent, 3.7 per cent and 7.6 per cent, respectively.

The influence of the amount of the solution used is greatest in the case of the loam soil. There appears here to be a considerable difference in the amount

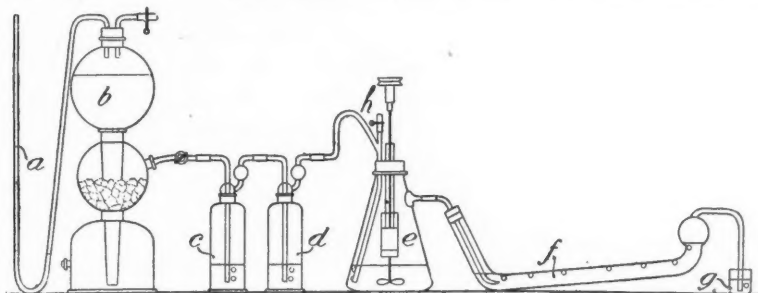


FIG. 3. APPARATUS FOR DETERMINING THE ACIDITY OF THE SOIL ACCORDING TO THE TACKE-SÜCHTING METHOD

of acid freed according to whether 300 cc. or 400 cc. of the solution is used. In the case of both the humus soils, approximately the maximum amount of acid is freed in the given reaction-time when 300 cc. of the solution is used. A test has been made in which 500 cc. of solution was used with the last-named peat, but this increase in the amount of the solution gives no appreciable change in the acid freed.

As mentioned before, Gully (16), in his latest work in investigating the ability of sphagnum-peat to free acid, has suggested using 3 grams of air-dry peat with 250 cc. of 10 per cent calcium acetate solution in a reaction-time of three hours. When the relation between the amount of peat and the amount of solution is so close, this reaction-time is sometimes insufficient, especially when an approximately absolute expression of the ability of high-bog peat to free acid in calcium acetate solution is to be obtained. According to the investigations referred to in table 2, in which the relation between the amount of peat and the amount of solution has been far wider than Gully suggested, base-absorption from high-bog peat is only approximately com-

plete after five hours have elapsed. Judging further from the results shown in table 1, it is not usually advisable to use more of this nor of any other peat soil, than corresponds to 0.5 to 0.75 gram of dry peat with 300 cc. of solution. Investigations show that for low-bog peat and silt-soil a three-hour reaction-time is quite insufficient. Finally, in order to express in exact figures the ability of mineral-soils to free acid, we must use much larger quantities of soil. When the reaction-time is increased to at least five hours we could, judging by the results of the experiments at hand, advantageously use about 10 grams of soil to 300 cc. of solution.

A wholly satisfactory expression of the power of the soil to free acid from salts can, however, be obtained only by varying the relation between the amount of soil and the amount of solution. This method seems especially advisable when we are dealing with mineral soils. Reference, too, should be made to the calcium-acetate method for determining the ability of the soil to free acid tested by investigations, and following later (p. 149).

b. Investigations of the variations in the ability of soils to free acid from calcium acetate, and the influence which air-drying exerts on this ability. Taking for granted that the ability of the soil to free acid from acetates, is chiefly determined by surface effects, there might be reason to suppose that drying the soil (due to the presence of non-reversible colloids), might cause a diminution of the soil-surface, and therefore of the power of the soil to adsorb bases.

To throw further light on the question the investigations referred to in tables 4 to 6 were made. They include both humus and field (mineral) soils.

All the soil-specimens were examined both in their original moist condition, and after being rendered air-dry. Duplicate determinations were generally made, the method being as follows. The soil was simultaneously weighed off into four retorts. Two of these were immediately filled with 300 cc. of calcium-acetate solution, while the two remaining were first used when the soil in them had been in an air-dry condition during a longer or shorter period (varying from a few days to several weeks).

At the time at which these tests were made, the investigations of the reaction-time mentioned above had been brought only to a temporary conclusion. As these investigations, as we have said before, seemed to indicate that a five-hour reaction-time (a reasonable quantity of soil being used) was sufficient for attaining the approximately maximum amount of acid freed, this reaction-time was chosen. Later investigations showed that this is insufficient for some humus soils, and therefore the results in table 4, are not in every instance absolute. However, they can doubtless express approximately the influence of air-drying on the ability of the soil to free acid from acetates and the variations in that ability.

If we look first at section 1, table 4, which contains results of tests made with raw peat soils, we see that here there is a comparatively small difference

between the ability of peat soil to free acid from calcium acetate before and after air-drying. Yet the results contain the suggestion that high-bog peat and low-bog peat respond differently to air-drying, for two of the three high-bog peat samples examined showed a little smaller, and both of the low-bog peat samples examined a greater ability to free acid when air-dry than when in their original fresh moist condition.

Results from the second section of the table show likewise that air-drying has in the case of low-bog peat caused an appreciable increase in the amount of acid freed. However, the three humus soils, marked "silt soils (nos. 12, 4 and 5), show a different result, for air-drying has to a great extent diminished their power to free acid.

As silt soils, in contrast to peat soils, dry into very hard lumps, it seemed possible that some of the soil in these lumps was never, or in any case, for an insufficient length of time, subjected to the influence of the calcium acetate solution. Therefore, tests were made, referred to in table 5, in pulverizing the soil in a mortar before placing it in the retort.

As the table shows, this precaution has entirely changed the relation. Now the air-dry samples show themselves capable of freeing considerably more acid than the fresh moist samples, and in all three instances the difference is far greater than in the case of any of the low-bog peat samples cited in table 4.

The variation in the ability of humus soils to free acids, is, as table 4 indicates, very large (from 2.2 to 12.7 cc. of 1/10 N acid per gram of air-dry soil). This variation is not only due to a varying content of mineral-soil, but also to a difference in the quality of the humus materials themselves. Low-bog peat generally possesses a much smaller ability to free acid than high-bog peat—due perhaps to the fact that the former humus form is much richer in bases (especially lime) than the latter.

As has been described in greater detail in a previous paper (11), the upper layer of peat (to a depth of 30 cm.), in high-bog peats possesses a far greater ability to free acids than the layer of peat lying just below it (30 to 50 cm.). This difference could not be explained by a difference in base-content, for the lower layer of peat was poorer in lime than the upper. As these peat specimens were in every instance pure peat, with approximately equally large surface (hygroscopicity, determined according to Mitscherlich and Rodewald). it is reasonable to infer that the ability of high-bog peat to free acid is not dependent on surface effects alone, and that the difference in this ability in the two layers of peat is due to a varying content of true acids. [See further article (11), p. 632.]

For the results of the tests made with field soils (mineral soils), see table 6.

As appears from the last column in this table, air-drying has in no single instance diminished the ability of the soil to free acid, but has in each case increased that ability to a distinct degree. In certain instances, especially in the case of soils with small power to free acid, this increase, relatively seen,

TABLE 4

Investigations of the ability of various humus soils to free acids both when fresh and moist and when air-dry (reaction-time five hours)

MARK	GENERAL CONDITION OF THE SOIL	ACID EFFERVESCENCE	REACTION	AZOTOBACTOR	VEGETATION		ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID USING								DIFFERENCE BETWEEN MOIST AND AIR-DRY PEAT SOIL
					GRAMS SOIL USED		Fresh, moist peat soil				Air-dry peat soil				
					Fresh moist	Dry soil	Per 100 cc. liquid		Per 1 gram dry peat soil	Per 100 cc. liquid		Per 1 gram dry peat soil			
							Single retorts	Average		Single retorts	Average				
Series 1. Raw Humus Soils															
A	High-bog peat from "St. Vildmose"	None	Strong acid	0	3	0.389	1.76	1.77	13.6	1.64	1.65	12.7	+0.9		
							1.78			1.64					
							1.76			1.66					
II	High-bog peat from "Vejen Mose"	—	—	0	3	0.487	1.46	1.46	9.0	1.42	1.41	8.6	+0.4		
							1.46			1.40					
M. D. L.	High-bog peat, quite unhumified sphagnum peat	—	—	0	3	0.333	0.90	0.90	8.1	0.94	0.94	8.5	-0.4		
							0.90			0.94					
B	Low-bog peat from Tylstrup	—	—	0	3	0.952	2.16	2.15	6.8	2.30	2.31	7.3	-0.5		
							2.08			2.36					
							2.20			2.28					
C	Low-bog peat from Gelleruplund	—	?	?	3	0.687	1.20	1.20	5.2	1.30	1.24	5.4	-0.2		
							1.20			1.18					
Series 2. Cultivated Humus Soils															
12	Peat mixed with silt and ochre	None	Acid	0	5	1.02	2.07	2.08	6.12	1.60	1.73	5.09	+1.03		
							2.09			1.86					
2	Peat soil mixed with sand	—	Slightly acid	0	3	1.18	2.25		5.72	2.29		5.82	-0.10		
22	Brownish black peat soil	—	Neutral	1	3	0.97	1.56		4.83	1.62		5.02	-0.19		
4	Silt soil	—	Neutral—slightly acid	0	5	1.55	2.22		4.29	1.53		2.96	+1.33		
1	Black peat soil mixed with sand	—	Neutral	2	5	1.86	2.36		3.82	2.63		4.25	-0.43		
5	Silt soil, not entirely humified	—	Neutral—slightly acid	0	6	2.10	2.46		3.51	1.93		2.76	+0.75		

TABLE 4 (Cont.)

MARK	GENERAL CONDITION OF THE SOIL	ACID EFFERVESCENCE	REACTION	AZOTOBACTER VEGETATION	GRAMS SOIL USED		ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID USING						DIFFERENCE BETWEEN FRESH AND AIR-DRY PEAT SOIL	
							Fresh, moist peat soil			Air-dry peat soil				
					Fresh, moist	Dry soil	Per 100 cc. liquid		Per 1 gm. dry peat soil	Per 100 cc. liquid		Per 1 gm. dry peat soil		
							Single retorts	Average		Single retorts	Average			
15	Black peat soil mixed with sand, not entirely humified	—	Neutral—slightly alkaline	2	5	1.65	1.83		3.33	1.81		3.30	+0.03	
6	Black peat soil mixed with sand	—	Neutral	4	6	2.50	1.63		1.96	1.87		2.24	−0.28	
21	Black peat soil mixed with sand	—	Neutral	4	5	1.82	1.30		2.13	1.40		2.30	−0.17	

Series 2. Cultivated Humus Soils

TABLE 5

Investigations of the influence of air-drying and pulverization on the ability of silt soils to free acids (reaction-time five hours)

MARK	SERIES 1										SERIES 2									
	Grams soil used		Acid freed, expressed in cubic centimeters 1/10 N acid using:						Difference between fresh, moist and air-dry (lumpy) soil	Grams soil used		Acid freed, expressed in cubic centimeters 1/10 N acid, using air-dry and pulverized soil						Difference between air-dry (lumpy) and air-dry pulverized soil	DIFFERENCE BETWEEN FRESH, MOIST AND AIR-DRY PULVERIZED SOIL	
			Fresh moist soil			Air-dry (lumpy) soil						Per 100 cc. liquid			Per 1 gram oven-dry soil					
			Per 100 cc. liquid		Per 1 gram oven-dry soil	Per 100 cc. liquid		Per 1 gram oven-dry soil				Per 100 cc. liquid		Per 1 gram oven-dry soil	Per 100 cc. liquid		Per 1 gram oven-dry soil			
			The single retorts	Average		The single retorts	Average					The single retorts	Average		The single retorts	Average				The single retorts
12	5	0.877	1.86	1.86	6.37	1.32	1.31	4.49	+1.88	0.97	0.837	2.10	2.12	7.60	-3.11	-1.23				
			1.86			1.30						2.14								
4	5	1.243	1.82	1.84	4.44	1.32	1.24	3.00	+1.44	1.37	1.252	2.08	2.06	4.94	-1.94	-0.50				
			1.86			1.16						2.04								
5	5	1.575	2.02	2.00	3.81	1.54	1.55	2.95	+0.86	1.73	1.586	2.42	2.42	4.57	-1.62	-0.76				
			1.98			1.56						2.42								

is very considerable. The last two soils mentioned in the table, nos. 1262 and 136, show that the power to free acid is, respectively, two and four times as great in air-dry as in moist soil. Air-drying has just the opposite effect on the majority of humus and mineral soils from what we expected to find (see introduction, p. 140).

It is very interesting to note that all the soils examined, even those effervescing strongly for acid and showing a strong alkaline reaction for litmus, possess a base-absorbing power.

In his "Bodenkunde," published in 1911, E. Ramann (21, p. 242), distinguishes between absorptively un-saturate ("absorptiv ungesättigte"), and absorptively saturate ("absorptiv gesättigte"), soils. In the first group he places the soils hitherto called "acid," and he defines them as "soils which are capable of coloring blue litmus paper red, and freeing acids in solutions of neutral salts." In the second group he places those soils which are base-saturate, and therefore incapable of absorbing bases. In the first group Ramann distinguishes further between neutrally reacting soils, which are only slightly stable, and will sooner or later become absorptively unsaturate, and alkaline reacting soils (those containing carbonate of lime or ammonium carbonate).

As the results of the investigations previously mentioned show, the premises for this division of the soils are incorrect, for we find that not only soil with an acid reaction for litmus, but also those with a neutral or alkaline reaction, possess the ability to absorb bases, and in an ordinary litmus test the means for determining whether or not the soil is "absorptively saturate," are wanting.

The fact that there is no close connection between the ability of the soil to free acid from calcium-acetate and its relation to litmus solution, and that soil may have a very great ability to free acid and still show no acid reaction for litmus,¹¹ seems to suggest that the red color does not appear in the litmus solution as a result of the base-adsorption of negative electrical soil colloids (which Ramann, in agreement with the opinion expressed by Baumann and Gully insists), but must be considered to express the fact that the soil contains *truly acid reacting substances*. Here, and in what follows, *these substances are to be understood as substances which in solution cause a greater hydrogen-ion concentration than would correspond to the value 10^{-7} [or to a hydrogen-ion exponent (P_H) = 7]*.

The author of the present article, collaborating with O. H. Larsen (10), has made investigations of the methods to be used in determining the lime-requirement of the soil. From these it appeared that when a determination

¹¹ In low-bog peat showing a neutral reaction for litmus, the ability to free acids can, as Table IV indicates, be almost as great as in low-bog peat showing acid reaction for litmus. In field-soils many examples (table 6) may be found in which soils with neutral reaction for litmus possess a greater ability to free acids, than soils showing a decided acid reaction for that indicator.

had been made of the reaction of the soil for litmus, and its relation to *Azotobacter*, we possessed a comparatively sure means of determining this requirement. As the results here given, table 6, show there is no definite relation between the reaction of the soil or its power to cause *Azotobacter* development, and its ability to free acid as measured by the acetate method, it is scarcely probable that this method will be of assistance in expressing quantitatively, to a sufficiently correct degree, the lime-requirement of the soil, or as Loew (20, p. 7) in mentioning the acetate method he himself recommends, expresses it—the need for that amount of lime necessary for neutralizing the soil. Whether the remaining methods which have been suggested (see further, pp. 116, 123) will give better results, must for the present remain doubtful. In any case it is incorrect to assume that the values found by these methods for expressing the ability of the soil to absorb bases also express quantitatively the degree of the lime-requirement of the soil, an assumption, which, as has been mentioned before, is very general.

The variation in the ability of field soils to free acids is found to be very great, just as in the case of humus soils. In fresh moist soils the figures expressing the amount of acid freed per unit of weight vary from 13.18 to 0.18, and when the soil is air-dry from 14.05 to 0.63. As table 6 indicates, the six soils having the greatest power of freeing acid show an acid reaction for litmus, while the nine soils with the smallest power of freeing acid show an alkaline reaction for litmus, but within these broad limits, as I have said before, there is no connection between the reaction of the soil for litmus (or its relation to *Azotobacter*) and its power to free acid from calcium acetate.

The freeing of 1 cc. of 1/10 N acid per gram of dry soil corresponds to the absorption of 2 grams of calcium per kilogram of dry soil. If we estimate that the upper 20 cm. of the field soils (the ordinary ploughed layer) contains 2,400,000 kgm. of air-dry soil per hectare, and assume that bases are absorbed by the soil to the same extent as in the retorts, then this layer has the power to absorb 4800 kgm. of calcium (equal to that amount of calcium found in 12,000 kgm. of carbonate of lime) for every cubic centimeter of 1/10 N acid which 1 gram of soil is able to free from the calcium acetate solution.

The field soil having the greatest power to free acids (no. 761, table 6), will under the given conditions absorb lime in $1.318 \times 12,000 = ca. 16,000$ kgm. of carbonate of lime per hectare (or a corresponding amount of other bases), whereas the soil with the smallest power to free acids (no. 136), will be able to absorb only that amount of lime found in $0.018 \times 12,000 = ca. 200$ kgm. of carbonate of lime per hectare.

If we assume further that raw high-bog peat contains 220,000 kgm. of dry soil, and raw fen peat 400,000 kgm. of dry soil per hectare in a depth of 20 cm. [cf. statements in article (11), table 2, p. 612] the amount of lime (estimated as carbonate) which this layer of peat can absorb per hectare; will in the case of the peat soils mentioned in table 4, series 1, vary from 8820 to 14,960 and 10,400 to 13,600. The ability of the raw peat

TABLE 6

Investigations of the ability of various field soils (mineral soils) to free acid both when fresh and moist, and when air-dry (reaction-time five hours)

MARK	GENERAL CONDITION OF THE SOIL*	ACID EFFERVES- CENCE	REACTION	AZOTOBACTER VEGETATION	PER CENT OF WATER IN THE SOIL†	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID USING								DIFFERENCE BETWEEN MOIST AND AIR-DRY SOIL
						Fresh, moist soil (10 gm.)				Air-dry soil				
						Per 100 cc. liquid		Per 10 gm. air-dry soil	Per 100 cc. liquid		Per 10 gm. air-dry soil			
						The single retorts	Average		The single retorts	Average				
761	Loamy, fine-grained dark sandy soil (8)	None	Acid	0	24	3.29	3.33	13.16	3.54	3.56	14.05	-0.89		
						3.37			3.58					
10	Very light dark sandy soil, poorly humified (2)	—	Acid	0	14	2.51		8.78	2.51		8.78	±0		
682	Light sandy soil, poor in humus (2)	—	Acid	0	13	2.02	2.08	7.17						
						2.13								
1235	Very light coarse grained sandy soil (1)	—	Slightly acid	0	23	1.70	1.71	6.66	2.04	2.07	8.06	-1.40		
						1.72			2.10					
901	Clay soil (7)	—	Acid	0	17	1.70	1.72	6.22						
						1.74								
1259	Sandy loam soil, poor in humus (4)	—	Slightly acid	0	7	1.89	1.86	6.00	2.01	2.06	6.65	-0.65		
						1.82			2.10					
1260	Loam soil (6)	—	Neutral	4	13	1.77	1.72	5.93	2.11	2.09	7.21	-1.28		
						1.67			2.06					
775	Light sandy soil, rather rich in humus (4)	—	Slightly acid	0	12	1.63	1.65	5.63	1.72	1.72	5.86	-0.23		
						1.67			1.72					
321	Good sandy soil (4)	—	Neutral	?	14	1.52	1.51	5.27	1.80	1.77	6.18	-0.91		
						1.50			1.74					
1240	Loam soil, rather poor in humus (5)	—	Slightly acid	0	10	1.52	1.50	5.00	1.66	1.66	5.53	-0.53		
						1.47			1.66					
3	Light fine-grained sandy soil (3)	—	Neutral	0-1	12	1.46		4.98	1.78		6.07	-1.09		
13	Good sandy soil, rich in humus (7)	—	Neutral	2	22	1.22		4.69	1.21		4.65	+0.04		

TABLE 6 (Cont.)

MARK	GENERAL CONDITION OF THE SOIL*	ACID EFFERVESCENCE	REACTION	AZOTOBACTER VEGETATION	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID USING								DIFFERENCE BETWEEN MOIST AND AIR-DRY SOIL			
					PER CENT OF WATER IN THE SOIL†											
					Fresh, moist soil (10 gm.)						Air-dry soil†					
					Per 100 cc. liquid		Per 10 gm. air-dry soil		Per 100 cc. liquid		Per 10 gm. air-dry soil					
	The single retorts	Average		The single retorts	Average		The single retorts	Average		The single retorts	Average					
1242	Light sandy soil, very poor in humus (1)	—	Neutral	1	11	1.29	1.30	4.38	1.53	1.55	5.22	—0.84				
17	Light sandy soil, poor in humus, marled for 2 years before sample was taken (2)	Rather strong	Neutral	0	7	1.34		4.32	1.46		4.71	—0.39				
2662	Clay soil (6)	None	Acid	0	11	1.24		4.18	1.32		4.45	—0.27				
745	Light sandy soil (3)	—	Neutral	0	8	1.27	1.27	4.14	1.47	1.46	4.76	—0.62				
744	Light sandy soil (3)	—	Neutral—slightly acid	0	9	1.27	1.25	4.12	1.47	1.45	4.78	—0.66				
727	Clay soil (6)	—	Neutral	3	15	1.16	1.15	4.06	1.16	1.19	4.20	—0.14				
14	Good sandy soil, rather rich in humus (5)	None	Neutral—slightly alkaline	4	14	0.94		3.28	1.03		3.59	—0.31				
786	Sandy loam soil (5)	—	Neutral—slightly alkaline	4	14	0.91	0.93	3.24	0.99	1.00	3.49	—0.25				
728	Clay soil (7)	—	Neutral	4	13	0.91	0.89	3.07	0.99	1.00	3.45	—0.38				
18	Light sandy soil, poor in humus (2)	—	Neutral	0	15	0.70		2.47	0.82		2.89	—0.42				
7	Clay soil, rich in humus (12)	None—very slight	Alkaline	4	18	0.68		2.46	1.11		4.01	—1.55				
16	Very light sandy soil, poor in humus (1)	None	Neutral	0	6	0.76		2.43	0.83		2.65	—0.22				
9	Loam soil (6)	Very slight	Slightly alkaline	4	15	0.62		2.19	0.68		2.40	—0.21				

TABLE 6 (Cont.)

MARK	GENERAL CONDITION OF THE SOIL*	ACID EFFERVES- CENCE	REACTION	AZOTOBACTER VEGETATION	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID USING								DIFFERENCE BETWEEN MOIST AND AIR-DRY SOIL
					Fresh, moist soil (10 gm.)				Air-dry soil				
					Per 100 cc. liquid		Per 10 gm. air-dry soil		Per 100 cc. liquid		Per 10 gm. air-dry soil		
					The single retorts	Average	Per 10 gm. air-dry soil	The single retorts	Average	Per 10 gm. air-dry soil			
11	Light sandy soil (3)	None—very slight	Slightly alkaline	4	9	0.64		2.11	0.77		2.54	—0.43	
773	Dark sandy soil, rather rich in humus (5)	None	Slightly alkaline	4	13	0.56	0.56	1.93	0.71	0.76	2.62	—0.69	
8	Clay soil (7)	Very slight	Alkaline	4	15	0.52		1.84	0.52		1.84	=0	
790	Clay soil, rich in humus (10)	Very slight	Slightly alkaline	4	24	0.46	0.44	1.74	0.76	0.76	3.00	—1.26	
800	Dark sandy soil, rich in humus (7)	Slight	Alkaline	4	31	0.42	0.40	1.74	0.56	0.56	2.43	—0.69	
a	Clay soil, rich in humus (10)	Strong	Alkaline	4	6	0.44		1.40					
1262	Sandy loam soil, poor in humus (4)	Slight	Alkaline	4	7	0.28	0.28	0.90	0.62	0.61	1.97	—1.07	
736	Clay soil, poor in humus (6)	None	Alkaline	4	15	0.07	0.05	0.18	0.23	0.23	0.81	—0.63	

* The figures in parentheses indicate the degree of heaviness of the soil.

† In the case of field soils the percentage of water is determined by air-drying.

soils to absorb bases (estimated per cubic measure) is not greater than that of several field soils.

The absorption of basic substances depends naturally on their being rendered soluble. Carbonate of lime is, for the most part, held in solution by the soil water, as bicarbonate of lime. The lime in this compound is doubtless absorbed very quickly by the soil—presumably more quickly and completely than when it appears as an acetate. Therefore the rapidity with which the lime is absorbed by “non-base saturate” soil is more than probably dependent on how soon it is rendered soluble. This, in turn, depends on the amount of moisture in the soil which in a given time has an opportunity of affecting the lime.

The author has previously had an opportunity of making investigations in connection with field experiments under the leadership of F. Kölpin Ravn,

(22) at the Askov Experiment Station, as to the use of lime as a preventive for club-root (*Plasmodeophora brassicae*). In the loam soils used it was found, that lime may be absorbed very quickly from carbonate of lime, even in soils showing a neutral reaction for litmus. In the soils which in 1906 were treated with *ca.* 4000 kgm. of CaCO_3 per hectare no carbonates could be found $4\frac{1}{2}$ years later under an examination, in which the acid test was used (sprinkling the soil with diluted HCl). Even when 12,000 kgm. of CaCO_3 were used per hectare, after the same length of time had elapsed, only a very slight effervescence was apparent in three of the four replicate plots. By the acid test made in 1911, two of the four replicate plots, which for four years (1902-1906) received an annual dose of *ca.* 3000 kgm. of CaCO_3 per hectare—12,000 kgm. in all—showed only a slight effervescence when acid was added, while specimens from the two remaining plots showed no effervescence whatsoever. As this acid test indicates the presence of very small amounts of carbonates in the soil, and the loss of carbonate of lime by washing-out during these few years cannot have been very great, these results may be considered an indication that the amount of calcium absorbed by the soil from the calcium carbonate, may attain quite a considerable dimension within a comparatively short period of time. In regard to the influence of this condition upon the power of carbonate of lime to change the reaction of the soil, see the paper (22) mentioned above.

Based on the results mentioned before, the following suggestion for a method for determining the power of the soil to free acids from calcium acetate is made.

Into a retort with a capacity of at least 400 cc., measure off 300 cc. of calcium acetate solution (10 grams of calcium acetate to 100 cc. of distilled water). Place in the retort fresh moist soil specimens, taking of pure humus soils (i.e., unmixed with mineral matter) as much of the finely divided mass as would correspond to about 0.5 gram of oven-dry soil, and of mineral soils (field soils) as much as would correspond to about 10 grams of air-dry soil. The reaction-time must be at least ten hours.¹² During the first and last part of the reaction-time the retorts are to be shaken repeatedly. As to methods of procedure for filtering and titrating, see the report, page 123.

When especially complete and accurate information as to the ability of the soil to free acid is wanted, it will be necessary, as we have mentioned before, to vary the relation between the amount of soil and the amount of solution. Of peat soils two different quantities might be used, corresponding to 0.5 gram and 2 grams of oven-dry peat, and of mineral soils two quantities corresponding to 10 grams and 20 grams of air-dry soil (to 300 cc. of acetate solution). As the results of the duplicate determinations always agree, always

¹² Even though a reaction-time of ten hours based on the investigations already made, might seem sufficient to attain the maximum amount of acid freed, yet in order to arrange laboratory work in a practical way, it is advisable to use a longer reaction-time. The soil might be placed in the retorts about 2 hours before the laboratory is closed. The retorts stand over night, and a filtration is made the next morning.

supposing that no serious errors have been made, a repetition of the investigation may be omitted, especially when two different quantities of soil have been used, for the results here obtained control each other to a certain extent.

The results of the investigations are given, for humus soils in cubic centimeters of 1/10 N acid per gram of oven-dry soil, and for mineral soils in cubic centimeters of 1/10 N acid per gram (or 10 grams) of air-dry soil, for in the latter case the amount of water hygroscopically bound is so small that it may be omitted in calculating the results.

3. *Determination of the ability of the soil to free acid from calcium-carbonate by means of the Tacke-Süchting method*

The principle underlying this method is mentioned on page 116. The apparatus used, shown in figure 3, page 139, corresponds very closely to that used by Tacke and Süchting [and described by Tacke in paper (30)]. The method used in making the determinations, which also for the most part corresponds to that used by the two scientists, was as follows.

Moist soil, finely minced in a meat-chopper, is placed in a reaction-retort (*e*) and from the hydrogen-generating apparatus (*b*), which in order to increase the hydrogen pressure is equipped with a manometer-tube (*a*) with mercury, hydrogen is led through a side tube into the reaction retort. Before the hydrogen reaches this, it has passed through two washing bottles (*c* and *d*) containing strong sulfuric acid and strong sodium hydroxide, respectively. The combined hydrogen and carbonic acid current now passes from the reaction-retort through a Pettenkofer absorption tube (*f*), containing 100 cc. of diluted sodium hydroxide (*ca.* 1/10 N), and is finally led off into a beaker (*g*) half-full of water. The speed of the hydrogen current is regulated by means of a stop-cock (*h*) on the side-tube of the hydrogen-generating apparatus. The agitator, with a mercury stopper, is driven by an electro-motor.

The peat soil, weighed off, is placed in the reaction-retort. This is supplied with water [Tacke (30, p. 121), mentions that the retorts are half filled with water], and a not too large surplus of carbonate of lime added. After an elongation of the tube projecting from the reaction-retort has been placed under water in a beaker, a hydrogen current (*ca.* two bubbles per second) is passed through the apparatus in order to drive off the carbonic acid generated by the action of the carbonate of lime on the peat soils. (This according to Tacke and Süchting will be accomplished after two hours.) The absorption tube is now nearly filled with *ca.* 1/10 N sodium hydroxide, and connected with the apparatus. Now about 50 cc. of 20 per cent HCl is poured through the tube (*h*), which has been connected with a separatory, and the carbonic acid freed from the remaining carbonate of lime is conducted by help of the hydrogen current, and under continual agitating through the absorption-tube. (According to Tacke and Süchting a hydrogen current for an hour is sufficient to drive off the entire amount of CO₂).

While Tacke and Süchting have determined the content of CO₂ in the receiver by titrating according to Cl. Winkler's method (adding pure barium chloride, and titrating with 1/5 or 1/10 N HCl, using phenolphthalein as an indicator), here the following method, which is very easy to work with, has been used.

From the 100 cc. of sodium hydroxide in the Pettenkofer tube, take 40 cc. and to it add 25 cc. of a 5 per cent barium chloride solution. After the pre-

precipitated barium carbonate has been removed by filtering, 50 cc. of the filtrate should be taken and this portion titrated with HCl, using methyl-orange as an indicator.

By multiplying the value found with $\frac{65 \times 100}{50 \times 40} = 3.25$ the total amount of NaOH in the Pettenkofer tube may be estimated, and by subtracting this amount from the amount of NaOH originally present, we have an expression for the amount of CO_2 freed. The amount of NaOH in the sodium hydroxide solution in its original form is determined in a similar fashion. One cubic centimeter 1/10 N NaOH corresponds to 0.0022 gram of CO_2 .

TABLE 7
Influence of the amount of peat used upon the ability to free CO_2

AMOUNT OF PEAT		AMOUNT OF WATER: IN CUBIC CENTI-METERS	AMOUNT OF CaCO ₃ USED: IN GRAMS	GRAMS OF CO ₂						GRAMS OF CO ₂ PER 10 GRAMS PEAT
				Single determinations					Average	
Fresh, moist	Oven-dry			a	b	c	d	e		
				<i>High-bog peat A (stirred for 3 hours)</i>						
10	1.51	415	0.1747	0.0151	0.0138	0.0162	0.0160	0.0162	0.0155	0.0155
15	2.27	415	0.2005	0.0243	0.0305				0.0274	0.0183
20	3.02	415	0.1959	0.0384	0.0385				0.0385	0.0193
30	4.53	415	0.2199	0.0589	0.0539				0.0564	0.0188
<i>High-bog peat B (stirred for 3 hours)</i>										
10	1.47	200	0.1766	0.0241	0.0225				0.0233	0.0233
20	2.94	200	0.2115	0.0523	0.0459				0.0491	0.0246

The investigations of the Tacke-Süchting method aim to throw light on the following questions:

1. What influence may varying the amount of peat used have on freeing CO_2 , the amount of water being kept constant?
2. What influence may varying the amount of water used have on freeing CO_2 , the amount of peat being kept constant?
3. The influence of the reaction-time on the freeing of CO_2 .

The results of the investigations may be seen in tables 7 and 8.

If we first turn to table 7, we see that the results give no indication that an increase of the amount of peat has relatively reduced the CO_2 freed. Quite the contrary is true, for in high-bog peat specimen A this is smallest, when the smallest amount of peat is used. In high-bog peat specimen B approximately as large an amount of CO_2 is freed per weight unit of peat when a small amount of peat is used, as when a large amount is used.

Table 8 gives the results of investigations as to the influence which varying the amount of water and the reaction-time may exert upon freeing CO_2 ,

and here there is a much greater result from the factors tested than in the investigations mentioned before.

When the difference between the amounts of peat and of water is relatively small, the amount of CO_2 freed in the same period is greater than when the difference is large. Moreover, we find that the reaction-time exerts a very great influence on the amount of CO_2 freed, and that this influence is especially apparent when the largest amount of water is used. In high-bog peat specimen A, for example, more CO_2 is freed when the smallest amount of water is used with a reaction-time of three hours, than when the largest

TABLE 8
Influence of the reaction-time and the amount of water used upon the ability to free CO_2

REACTION TIME IN HOURS	RELATION BETWEEN AMOUNTS OF SOIL AND WATER	OVEN- DRY PEAT USED: IN GRAMS	AMOUNT OF CaCO ₃ USED: IN GRAMS	GRAMS OF CO ₂					Average
				Single determinations					
				a	b	c	d	e	
High-bog peat A									
3	10: 200	1. 51	0. 179	0. 0255	0. 0225	0. 0252			0. 0244
4	10: 200	1. 51	0. 191	0. 0263	0. 0265				0. 0264
1	10: 415	1. 51	0. 164	0. 0067	0. 0056				0. 0062
2	10: 415	1. 51	0. 166	0. 0124	0. 0128				0. 0126
3	10: 415	1. 51	0. 175	0. 0162	0. 0151	0. 0138	0. 0162	0. 0160	0. 0155
4	10: 415	1. 51	0. 165	0. 0198	0. 0192				0. 0195
6	10: 415	1. 51	0. 200	0. 0236	0. 0223				0. 0230
8	10: 415	1. 51	0. 211	0. 0252	0. 0211				(?)
High-bog peat B									
2	10. 3: 100	1. 51	0. 202	0. 0271	0. 0226				0. 0249
3	10. 3: 100	1. 51	0. 201	0. 0255	0. 0248				0. 0253
2	10. 3: 200	1. 51	0. 169	0. 0225	0. 0188				0. 0207
3	10. 3: 200	1. 51	0. 178	0. 0270	0. 0263				0. 0267
4	10. 3: 200	1. 51	0. 185	0. 0273	0. 0283				0. 0278
6	10. 3: 200	1. 51	0. 194	0. 0314	0. 0318				0. 0316

amount of water is used with a six-hour reaction-time. In the latter case CO_2 has not totally ceased to generate even when six hours have elapsed.

The investigations made with high-bog peat specimen B, in which the amount of water used was much smaller, seem also to indicate that CO_2 is freed most quickly when the smallest amount of water is used, even though this result does not appear very plainly because of poor agreement in the duplicate determinations. In a reaction-time of three hours, and when the largest amount of water is used (200 cc.), we have in this experiment just as great an amount of CO_2 as by using the smallest amount of water (100 cc.). But also, when so moderate an amount of water as 200 cc. is used, a long time

must elapse before the reaction between peat and lime ceases, for even after four hours CO_2 is still being generated.

In the investigations made by Süchting (27), using two different specimens of high-bog peat, a two-hour reaction-time has proved quite sufficient to bring the reaction to an end (27, p. 42). This result is opposed to the results of the investigations which we have here. For instance, from table 8 it appears that in high-bog peat nearly twice as much CO_2 is freed after six hours have passed, as after two hours, and that the amount of CO_2 freed increases gradually with the length of the reaction-time. As the amount of water used, as well as the reaction-time, determines the amount of CO_2 freed, it must be admitted that in this investigation, using the Tacke-Süchting method, it has been impossible to obtain an exact expression of the ability of the soil to free CO_2 from CaCO_3 . The author is unable to explain the great difference between Süchting's results and those given here. However, for the

TABLE 9
Investigations of the time required for airing with hydrogen

PEAT USED	RELATION BETWEEN AMOUNTS OF PEAT AND WATER USED	AMOUNT OF CaCO_3 USED: IN GRAMS	GRAMS OF CO_2 AFTER AIRING WITH HYDROGEN FOR			DIFFERENCE BETWEEN AIRING FOR 1 HOUR AND 3 HOURS		DIFFERENCE BETWEEN AIRING FOR 3 HOURS AND 5 HOURS	
			1 Hour	3 Hours	5 Hours	Grams	Percentage of CO_2 found after 1 hour	Grams	Percentage of CO_2 found after 3 hours
High-bog peat A....	10: 415	0.1741	0.0435	0.0604		0.0169	38.9		
High-bog peat A....	10: 415	0.1778		0.0618	0.0673			0.0055	8.9
High-bog peat B....	10. 3: 200	0.1780		0.0520	0.0541			0.0021	4.0

present, he will limit himself to stating, that the two-hour reaction-time suggested by Tacke and Süchting is in any case far too short to bring the reaction between high-bog peat and carbonate of lime to a complete close, and that in the investigations made here, as well as in those applied to the calcium acetate method, before mentioned, the length of the reaction-time to a far greater extent than the amount of peat used appears to determine the amount of acid freed per weight unit of peat.

Nor has it been possible to confirm Süchting's results in regard to the time necessary for bringing into the receiver the entire amount of CO_2 freed by the addition of HCl . According to Süchting's investigations, after hydrogen has been conducted through the apparatus for an hour no more CO_2 passes into the receiver, while according to our investigations no such constant results have been attained. By using a comparatively large amount of water, the difference between the amount of CO_2 collected after hydrogen has been conducted for one and three hours is so great, that it must to a large extent be due to the fact that the first-named period was insufficient for driving the

amount of CO_2 freed from calcium carbonate into the receiver, whereas the comparatively small differences in the amount of CO_2 after hydrogen has been conducted through the apparatus for three and five hours, may possibly be explained by internal reactions in the humus materials themselves.

In all the investigations referred to in tables 7 and 8, hydrogen has been conducted through the apparatus not only one, but three hours after hydrochloric acid has been added.

As an objection to the principle underlying the acetate method, Süchting (27, p. 23), criticizing an experiment made by Berthelot to obtain an expression for the acidity of the soil by determining the amount of acetic acid which a certain quantity of soil when heated with a solution of potassium acetate is able to free from that salt, emphasizes that aside from other weaknesses, by this method one is able only to determine the amount of soil acids

TABLE 10
Comparison between the amounts of acid freed, using the Tacke-Süchting method and the calcium acetate method

PEAT SOIL	AMOUNT OF ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID PER 1 GRAM OF OVEN-DRY PEAT			
	Tacke-Süchting method (Reaction-time 3 hours)		Calcium acetate method (6 grams moist peat to 300 cubic centimeters liquid)	
	Relation between amount of moist peat* and water		Reaction time	
	10:200	10:415	3 hours	5 hours
High-bog peat A.....	7.3	4.7	14.0	14.1
High-bog peat B.....	8.0		10.0	10.6

* Each peat sample contained 1.51 gram of oven-dry substance in 10 grams of moist peat.

which are stronger than acetic acid, and therefore the method gives us no accurate expression for the acidity of the soil.

In table 10 a comparison has been made between the calcium acetate method and the Tacke-Süchting method applied to investigations in freeing acid in high-bog peat specimens A and B (tables 7 and 8).

Although in the Tacke-Süchting method a three-hour instead of a two-hour reaction-time has been used, which must have increased the amount of CO_2 freed considerably (table 8), yet the method in every instance gives distinctly lower results than the calcium acetate method. The difference in results from the two methods is especially apparent in high-bog peat specimen A. Here the Tacke-Süchting method gives only about one-half as large results as the calcium acetate method when the smallest amount of water is used, and about one-third as large when the largest amount of water is used.

If, as does Süchting, we would take for granted, that the amount of calcium absorbed expresses the acidity of the soil, the figures appearing when this last-named method is used must more nearly approach the absolute value for this acidity than the figures appearing from the first method. Moreover, as the results from the acetate method show that there is far better concordance in the results from the duplicate determinations, it seems as if this method should be preferred to the Tacke-Süchting method, over which it has the additional advantage that it is quicker and more easy to work with.

II. QUALITATIVE DETERMINATION OF THE REACTION OF THE SOIL

1. Methods for making a qualitative determination of the reaction of the soil

In making a qualitative determination of the reaction of the soil, litmus paper is most frequently used, and the method is generally as follows [see, for instance, M. Weibull (33)]. A small portion of the soil sample is placed in a dish and moistened with enough water to give it, when stirred, a porridge-like consistency. A strip of red and a strip of blue litmus paper are now placed over the soil in such a way, that the paper at every point comes in contact with the soil particles. A few hours later the color changes in the litmus paper are observed and noted.

In making a qualitative determination of the soil reaction the author of this paper has used a neutral litmus solution. His method is described in detail in a previous paper (10, p. 431).

In 1908 Baumann and Gully (3) published a method for making a qualitative acidity determination based on the ability of free acids to free iodine from a solution of potassium iodide and potassium iodate.

The method is as follows.

Two grams of potassium iodide and 0.1 gram of potassium iodate are dissolved in 100 cc. of distilled water. One gram of peat soil (if mineral soil, a slightly larger portion) is placed in the retort, which is shaken frequently, and fifteen minutes later filtered. A few drops of the filtrate are placed in a thin starch water and the intensity of the blue color noted.

Recently Daikuhara (12) proposed the following method for making a qualitative determination of the acidity of the soil.¹³

Place 5 grams of soil in a test tube and add drop by drop a 10 per cent potassium nitrite solution until the soil is well moistened. The tube is corked with a wad of cotton, from which a strip of potassium iodide starch paper reaches down into the tube. After a short time the intensity of the blue color of the paper gives an indication as to the degree of the acidity of the soil. The potassium nitrite used must be chemically pure, and above all must not contain any potassium carbonate. Potassium nitrite is considered better in such investigations than sodium nitrite.

The results obtained from this method, as well as those from the Baumann-Gully method, can give only indications as to the intensity of the acidity of the soil, but no indication, as the litmus method to some extent does, as to the alkalinity of the soil.

¹³ This method is a modification of a method previously proposed by Oscar Loew (20).

2. *Comparison of various methods for making a qualitative determination of the reaction of the soil*

Considering the important part which a qualitative determination of the reaction and basicity of the soil has played in later years in soil investigations, a comparison of the most important methods suggested would seem to be of interest in this connection, and therefore the investigations referred to in table 11 have been made.

In these investigations the following methods have been used.

Litmus method (litmus test), with the use of both litmus solution and litmus paper. In investigating the question of the extent to which air-drying the soil affects its reaction, litmus solution being used, a determination was made of soil samples both in that condition of moisture which was present at the beginning of the experiment, and air-dry. Two equally large soil portions were simultaneously weighed off. One of these was placed in a test tube which was at once corked, and the other spread out on a piece of paper to become air-dry. After drying, this portion was likewise placed in a test tube and to each tube 20 cc. of neutral litmus solution added. Of mineral soil a portion was used corresponding to 5 grams of air-dry soil, and of fresh moist peat as much as would correspond to 1 gram of oven-dry peat.

Nitrite method. The one I have used is closely related to the one suggested by Daikuhara. However, in place of potassium nitrite, sodium nitrite is used, because neutral potassium nitrite could not be procured. A portion of the fresh moist soil corresponding to about 5 grams of air-dry soil was used. The reagent paper was moistened with distilled water before being submerged in the glass. It has been found important not to use more nitrite solution than is just sufficient to moisten the soil sample. In the presence of a greater amount of moisture the reaction is often irregular.

Iodine method (according to Baumann and Gully). For this method, see above. As the prepared solution of potassium iodide and potassium iodate showed a slightly acid reaction for litmus paper, and was distinctly yellow in color, it was neutralized before use with a very thin sodium hydroxide solution, and the color finally entirely removed by adding, drop by drop, a very thin sodium hyposulfite solution. With 100 cc. of the named solution of potassium iodide, and potassium iodate, a portion of mineral soil corresponding to 3 grams of air-dry soil was used. Besides noting the degree of the blue color in the starch water, the degree of the yellow color in the filtrate itself was noted, for this reaction seemed to give better and more complete information as to the acidity of the soil, than the starch water reaction. The degree of this last depends to a certain extent on the concentration of the starch water used, and it was found necessary to use a rather strongly diluted starch water. Observation of the blue color must be made immediately after the filtrate has been dropped, as the starch solution will, in any case after a short time, assume a blue color (due to the sensitiveness of the reagent to CO_2). Only

two shades of blue can be distinguished with positive certainty—light blue and blue.

In addition to these indicators, experiments have been made with *p*-nitrophenol. This substance, tested by S. P. L. Sørensen (23) in measuring hydrogen-ion concentration in approximately neutral stuffs, has proved to be a splendid indicator.¹⁴ Of this indicator, which, as far as is known, has not previously been used in making soil-reaction determinations, a solution of the following composition was prepared: 0.4 gram *p*-nitrophenol, 60 cc. of alcohol, and 940 cc. of distilled water. Twenty drops of the solution were used to 20 cc. of distilled water, which at once assumed a pale yellowish color. In this test the mineral soils used were always in an air-dry condition, and 5 grams taken for each determination. Peat soils were used in their original moist condition, and in the amount mentioned above. The soil and the solution were well shaken together and the observations of the color of the solution made the following day. Decidedly acid soils render the solution colorless, while slightly acid, neutral and alkaline soils color it yellow (varying from a very pale to a greenish yellow).

In connection with these qualitative investigations, quantitative determinations have been made, based on the calcium acetate method, and the Daikuhara potassium chloride method. In the former a portion of soil corresponding to 9 grams of air-dry field soil, or 0.5 gram of oven-dry peat soil, to 300 cc. of calcium acetate solution is used. The mixture stood for *ca.* eighteen hours, was shaken from time to time and titrated according to the method mentioned before. In the potassium chloride method of field soils a 100 gram portion of the fresh soil specimen, and of peat soils a portion corresponding to 10 grams of oven-dry peat, was weighed off to 250 cc. 1/1 N potassium chloride solution. The mixture stood for five days, being shaken from time to time. Half of the amount of fluid present (=125 cc. of potassium chloride solution plus half of the moisture found in the soil added), corresponding to half of the portion of soil used, is titrated (after having been filtered, and the free CO₂ removed by hasty boiling), with 1/10 N NaOH, phenolphthalein being used as the indicator. According to Daikuhara the content of acid found is multiplied by the factor 3, and thereby, as has been mentioned before, an approximately correct expression for the absolute acidity of the soil should be obtained (see further, page 117).

As is mentioned on page 117, Daikuhara states that the acidity of mineral soils is for the most part determined by the presence of acid aluminum—or (in certain instances), iron-compounds, and that the amount of these found in the potassium chloride solution corresponds very closely to the amount of NaOH used in titration.

¹⁴ Both *p*-nitrophenol and litmus belong to that group of indicators which S. P. L. Sørensen calls "indicators of the phosphate mixtures," and which are characterized by the fact that their turning-point is very close to the true neutral point ($P_H=7$). Litmus spans the hydrogen-ion domain: $P_H=ca. 4.5$ to 8.3 and *p*-nitrophenol the hydrogen-ion domain $P_H=5$ to 7 .

TABLE 11
Comparison of various methods for determining the reaction of the soil

SOIL SAMPLE NUMBER	ORDINARY CONDI- TION OF THE SOIL	PER CENT DRY MATTER IN THE SOIL	ACID EFFER- VESCENCE	AZOTOBACTER VEGETATION		REACTION FOR LITMUS SOLUTION		REACTION FOR LITMUS IN MIXTURE OF SOIL AND PO- TASSIUM CHLORIDE (RIDGE)	REACTION FOR SODIUM NITRITE (DAIRY- HARA'S METHOD) DEGREE OF BLUE	REACTION FOR POTASSIUM IODIDE AND POTASSIUM IODATE (BAUMANN AND GILLY'S METHOD)	REACTION FOR P-NITRO- PHENOL	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID			SIZE OF THE GELATINUS PRECIPITATE APPEARING WHEN KCl EXTRACT IS NEUTRALIZED WITH SODIUM HYDRAE		RELATION BETWEEN THE AMOUNT OF ACID FREED BY THE POTASSIUM CHLO- RIDE AND THE CALCIUM ACETATE METHOD		
						In moist condition	In air-dry condition					Per 3 grams air-dry soil	Per 100 grams air- dry soil	Per 50 grams moist soil	The absolute acid- ity per 100 grams				
1. Field Soils																			
3014	Good sandy soil, rather rich in humus (5)	90.4	None	0	Strong acid	Strong acid	Strong acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	3.06	102.0	1.77	11.8	Rather large	1: 8.6
3055	Loam soil, poor in humus (5)	90.4	None	0	Strong acid	Strong acid	Strong acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	1.91	63.7	5.50	35.5	Large	1: 1.8
3329	Loam soil (6)	83.2	None	0	Strong acid	Strong acid	Strong acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	2.74	91.3	5.78	41.7	Large	1: 2.2
3313	Clay soil, poor in humus (6)	87.2	None	0	Strong acid	Strong acid	Strong acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	4.00	133.3	21.85	150.3	Very large	1: 0.9
3305	Clay soil, poor in humus (8)	93.8	None	0	Strong acid	Strong acid	Strong acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	2.78	92.7	13.05	83.5	Large	1: 1.1
4066	Loam soil (5)	87.4	None	0	Strong acid	Strong acid	Strong acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	2.36	78.7	1.35	9.3	Small	1: 8.5
4031	Good sandy soil (4)	90.0	None	0	Strong acid	Strong acid	Strong acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	1.54	51.3	0.85	5.7	Very small	1: 9
4292	Good sandy soil, rather rich in humus (5)	88.4	None	0	Strong acid	Strong acid	Strong acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	4.50	150.0	5.25	35.6	Large	1: 4.2
4384	Light sandy loam soil (5)	91.0	None	0	Strong acid	Strong acid	Strong acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	1.38	46.0	3.33	22.0	Rather large	1: 2.1
4312	Good sandy soil, quite poor in humus (3)	91.2	None	0	Strong acid	Strong acid	Strong acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	1.78	59.3	4.75	31.3	Large	1: 1.9

		85.2	None	0	Strong acid	Strong acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	3.14	104.7	2.05	14.4	Rather large	1: 7.3
4718	Gray sandy soil, slightly mixed with peat (2)	85.2	None	0	Strong acid	Strong acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	3.14	104.7	2.05	14.4	Rather large	1: 7.3
1	Clay soil, poor in humus (6)	86.0	Very slight	0	Strong acid	Strong acid	Acid	Acid	Very strong	Yellow	Blue	Colorless	1.72	57.3	2.05	14.3	Rather large	1: 4.0
2	Clay soil, poor in humus (6)	86	Very slight	0	Strong acid	Strong acid	Acid	Acid	Very strong	Yellow	Blue	Very pale yellow	1.44	48.0	1.05	7.3	Small	1: 6.6
4097	Good sandy soil (4)	90.0	None	0	Acid	Acid	Slightly acid	Slightly acid	Very strong	Yellow	Light blue	Colorless	2.16	72.0	0.95	6.3	Small	1: 11.4
3015	Light sandy soil (3)	89.6	None	0	Acid	Strong acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	3.02	100.7	6.46	43.3	Large	1: 2.3
2977	Loam soil, rather poor in humus (5)	94.8	None	0	Acid	Acid	Slightly acid	Slightly acid	Very strong	Strong yellow	Blue	Colorless	2.84	94.7	1.80	11.4	Rather large	1: 8.3
2957	Good sandy soil (4)	90.2	None	0	Acid	Acid	Slightly acid	Slightly acid	Very strong	Strong yellow	Blue	Colorless	1.88	62.7	1.34	8.9	Small	1: 7.0
4028	Fine sandy soil, poor in humus (4)	91.0	None	0	Acid	Acid	Acid	Acid	Very strong	Yellow	Blue	Colorless	1.64	54.7	1.15	7.6	Small	1: 7.2
4067	Good sandy soil, rather rich in humus (5)	84.0	None	0	Acid	Acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	2.70	90.0	1.10	7.9	Small	1: 11.4
4062	Light fine sandy soil, rather poor in humus (3)	92.0	None	0	Acid	Strongly acid	Slightly acid	Slightly acid	Very strong	Pale yellow	Light blue	Colorless	1.40	46.7	0.65	4.2	None	1: 11.1
4083	Clay soil (8)	84.6	None	0	Acid	Acid	Acid	Acid	Very strong	Yellow	Blue	Colorless	1.52	50.7	0.33	2.3	None	1: 22.0
4332	Light sandy soil, poor in humus (2)	91.8	None	0	Acid	Acid	Acid	Acid	Very strong	Pale yellow	Light blue	Colorless	1.58	52.7	0.90	5.9	Very small	1: 8.9
4284	Sandy loam soil (5)	93.8	None	0	Acid	Slightly acid	Slightly acid	Slightly acid	Very strong	Yellow	Light blue	Colorless	1.30	43.3	0.86	5.5	None	1: 7.9
1946	Light, rather coarse sandy soil (2)	93.8	None	0	Slightly acid	Slightly acid	Slightly acid	Slightly acid	Very strong	Yellow	Blue	Colorless	1.38	46.0	1.15	7.4	Small	1: 6.2
2178	Loam soil (6)	92.0	None	0	Slightly acid	Slightly acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	1.52	50.7	1.60	10.4	Small	1: 4.9
3127	Loam soil (6)	94.8	None	0	Slightly acid	Slightly acid	Slightly acid	Slightly acid	Rather strong-slight	Yellow	Blue	Colorless	1.59	53.0	0.62	4.1	None	1: 12.9
3158	Loam soil, poor in humus (5)	93.8	None	0	Slightly acid	Slightly acid	Acid	Acid	Very strong	Strong yellow	Blue	Colorless	1.60	53.3				

TABLE 11 (Cont.)

SOIL SAMPLE NUMBER	ORDINARY CONDI- TION OF THE SOIL	PER CENT DRY MATTER IN THE SOIL	ACID EFFER- VESCENCE	AZOTOBACTER VEGETATION	REACTION FOR LITMUS SOLUTION		REACTION FOR LITMUS (SOIL FOR- EDGE)	REACTION FOR MIXTURE OF SOIL AND POTASSIUM CHLORIDE SOLUTION	REACTION FOR SODIUM NITRATE (DAIRY- HARA'S METHOD) DEGREE OF BLUE COLOR OF THE POTASSIUM IODIDE STARCH PAPER	REACTION FOR POTASSIUM IODIDE AND POTASSIUM IODATE (BAUMANN AND GULLY'S METHOD)		REACTION FOR P-NITRO- PHENOL	ACID FREED, EXPRESSED IN 1/10 N ACID			SIZE OF THE GELATINOUS PRECIPITATE APPEARING WHEN KCl EXTRACT IS ACIDIFIED BY THE POTASSIUM CALIO- METHOD	RELATION BETWEEN THE AMOUNT OF ACID FREED BY THE POTASSIUM CALIO- METHOD AND THE CALCIUM ACETATE	
					In moist condition	In air-dry condition				Color of the filtrate	Color of the starch solution		Per 3 grams air-dry soil	Per 100 grams air- dry soil	Per 50 grams moist soil			The absolute acid- ity per 100 grams air-dry soil
1. Field Soils																		
3114	Clay soil, poor in humus (6)	96.6	None	0	Slightly acid	Slightly acid	Slightly acid	Acid	Very strong	Yellow	Blue	Very pale yellow	0.92	30.7	0.30	1.9	None	1: 16.2
4042	Good sandy soil (4)	90.8	None	0	Slightly acid	Slightly acid	Slightly acid	Slightly acid	Strong	Yellow	Blue	Colorless —very pale yellow	1.52	50.7	0.25	1.7	None	1: 29.8
4079	Sandy loam soil, rather poor in humus (4)	85.0	None	0	Slightly acid	Slightly acid	Slightly acid	Slightly acid	Strong	Yellow	Blue	Colorless —very pale yellow	1.26	42.0	0.29	2.0	None	1: 21
4041	Clay soil (7)	85.6	None	0	Slightly acid	Slightly acid	Slightly acid	Acid	Rather strong	Pale yellow	Light blue	Very pale yellow	1.44	48.0	0.15	1.1	None	1: 43.6
4350	Light sandy soil (3)	89.0	None	0	Slightly acid	Slightly acid	Slightly acid	Acid	Very strong	Yellow	Colorless	Colorless	1.70	56.7	0.53	3.6	None	1: 15.8
4323	Light sandy soil (3)	88.4	None	0	Slightly acid	Slightly acid	Slightly acid	Neutral— slightly acid	Very strong	Pale yellow	Light blue	Very pale yellow	1.68	56.0	0.24	1.6	None	1: 35.0
1944	Light rather coarse sandy soil (2)	97.6	None	0	Neutral— slightly acid	Neutral— slightly acid	Slightly acid	Acid	Very strong	Yellow	Blue	Colorless	1.28	42.7	0.86	5.3	Small	1: 8.1
1919	Coarse sandy soil, very poor in humus (2)	98.0	None	0	Neutral— slightly acid	Neutral— slightly acid	Neutral— slightly acid	Slightly acid	Rather strong	Pale yellow	Blue	Colorless —very pale yellow	0.67	22.3	0.48	2.9	Small	1: 7.7

1. Field Soils

2982	Good sandy soil (4)	96.6	None	0	Neutral— slightly acid	Neutral— slightly acid	Slightly acid	Slightly acid	Strong	Yellow	Blue	Very pale yellow	1.90	63.3	0.75	1.6	None	1: 39.6
3073	Clay soil, poor in humus (6)	95.4	None	0	Neutral— slightly acid	Neutral— slightly acid	Neutral— slightly acid	Slightly acid	Slight	Yellow	Light blue	Very pale yellow	0.98	32.5	0.29	1.8	None	1: 18.1
2937	Good sandy soil (4)	93.0	None	0	Neutral— slightly acid	Neutral— slightly acid	Neutral	Neutral	Rather strong— slight	Pale yellow	Colorless	Very pale yellow	1.09	36.3	0.14	0.9	None	1: 40
4027	Clay soil, poor in humus (6)	90.0	None	0	Neutral— slightly acid	Neutral— slightly acid	Neutral— slightly acid	Neutral— slightly acid	Very strong	Yellow	Blue	Very pale yellow	1.48	49.3	0.15	1.0	None	1: 49.3
4044	Good sandy soil, rather rich in humus (5)	88.8	None	0	Neutral— slightly acid	Neutral— slightly acid	Neutral	Neutral	Very strong	Colorless	Colorless	Pale yellow	1.50	50.0	0.09	0.6	None	1: 83.3
4333	Light sandy soil (3)	88.2	None	0	Neutral— slightly acid	Neutral— slightly acid	Neutral— slightly acid	Neutral	Very strong	Very pale yellow	Colorless	Very pale yellow	1.56	52.0	0.25	1.7	None	1: 30.6
4376	Clay soil, rather rich in humus (9)	86.4	None	0	Neutral— slightly acid	Neutral— slightly acid	Neutral— slightly acid	Slightly acid	Very strong	Very pale yellow	Colorless	Very pale yellow	1.28	42.7	0.22	1.5	None	1: 28.5
2951	Good sandy soil, rich in humus (6)	91.8	None	0	Neutral	Neutral	Neutral— slightly alkaline	Slightly alkaline	Rather strong	Colorless	Colorless	Very pale yellow	2.11	70.3	0.12	0.8	None	1: 87.9
3074	Loam soil (6)	94.6	None	0	Neutral	Neutral	Slightly alkaline	Slightly alkaline	Strong— slight	Very pale yellow	Colorless	Very pale yellow	0.84	28.0	0.10	0.6	None	1: 46.7
27	Light sandy soil (3)	93.4	None	0			Slightly acid	Slightly acid	Very strong	Colorless	Colorless	Very pale yellow	0.80	26.7	0.10	0.6	None	1: 44.5
4088	Sandy loam soil, poor in humus (4)	84.4	None	0	Neutral	Neutral	Neutral— slightly acid	Neutral— slightly acid	Very strong	Colorless	Colorless	Very pale yellow	1.08	36.0	0.13	0.6	None	1: 60.0
4429	Sandy loam soil (5)	87.2	None	0	Neutral	Neutral	Neutral	Neutral	Rather strong	Colorless	Colorless	Very pale yellow	0.92	30.7	0.15	1.0	None	1: 30.7
4362	Good sandy soil, rich in humus (6)	86.2	None	0	Neutral	Neutral	Neutral	Neutral	Rather strong	Colorless	Colorless	Pale yellow	1.20	40.0	0.16	1.0	None	1: 40.0
4011	Sandy loam soil (5)	85.0	None	4	Neutral	Neutral	Neutral	Neutral	Slight	Colorless	Colorless	Pale yellow	0.96	32.0	0.15	1.1	None	1: 29.1
4045	Sandy loam soil, poor in humus (4)	88.0	None	4	Neutral	Neutral	Neutral	Neutral	Rather strong— slight	Very pale yellow	Colorless	Pale yellow	0.68	22.7	0.08	0.5	None	1: 45.4

TABLE 11 (Cont.)

SOIL SAMPLE NUMBER	ORDINARY CONDI- TION OF THE SOIL	PER CENT DRY MATTER IN THE SOIL	ACID EFFER- VESCENCE	AZOTOBACTER VEGETATION		REACTION FOR LITMUS SOLUTION		REACTION FOR LITMUS IN MIXTURE OF SOIL AND PO- TASSIUM CHLORIDE SOLUTION	REACTION FOR POTASSIUM IODIDE AND POTASSIUM IODATE (BAUMANN AND GULLY'S METHOD)		REACTION FOR P-NITRO- PHENOL	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS IN 1/10 N ACID				SIZE OF THE GELATINOUS PRECIPITATE APPEARING WHEN KCl EXTRACT IS NEUTRALIZED WITH SODIUM HYDROXIDE	RELATION BETWEEN THE AMOUNT OF ACID FREED BY THE POTASSIUM CHLO- RIDE AND THE CALCIUM ACETATE METHOD					
				In moist condition	In air-dry condition	Neutral	Slightly alkaline		Neutral— slightly acid	Neutral		Neutral— slightly alkaline	Slightly alkaline	Neutral	Colorless			Pale yellow	Per 3 grams air-dry soil†	Per 100 grams air soil†	Per 50 grams moist soil†	The absolute acid- ity per 100 grams air-dry soil†
1. Field Soils																						
2932	Good dark sandy soil, very rich in humus (8)	75.0	None	4	Neutral	Neutral	Slightly alkaline	Neutral	Neutral	None	Colorless	Pale yellow	1.38	46.0	0.14	1.1	None	1:41.8				
2909	Good sandy soil (4)	91.2	None	4	Neutral	Neutral	Neutral— slightly acid	Neutral	Strong	Strong	Colorless	Very pale yellow	0.80	26.7	0.05	0.3	None	1:89.0				
2923	Sandy loam soil (5)	91.8	None	4	Neutral	Neutral	Neutral	Neutral	Very strong	Very strong	Colorless	Very pale yellow	1.05	35.0	0.14	0.9	None	1:38.9				
3064	Loam soil, poor in humus (5)	92.6	Very slight	4	Neutral	Neutral— slightly alkaline	Slightly alkaline	Slightly alkaline	Very slight	Very slight	Colorless	Pale yellow	0.61	20.3	0.10	0.6	None	1:33.8				
3081	Sandy loam soil (5)	93.2	None	4	Neutral	Neutral— slightly alkaline	Slightly alkaline	Slightly alkaline	None	None	Colorless	Pale yellow	0.52	17.3	0.10	0.6	None	1:28.8				
2922	Sandy loam soil (5)	90.0	None	4	Neutral	Neutral	Neutral	Neutral	Strong	Strong	Colorless	Pale yellow	1.01	33.7	0.14	0.9	None	1:37.4				
3058	Clay soil, poor in humus (6)	97.2	None	4	Neutral	Neutral	Neutral	Neutral	None	None	Colorless	Pale yellow	1.24	41.3	0.10	0.6	None	1:68.8				
3141	Clay soil (9)	83.0	None	4	Neutral	Neutral— slightly alkaline	Neutral	Neutral	Very slight	Very slight	Colorless	Pale yellow	1.18	39.3	0.10	0.7	None	1:56.1				

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2160	Good sandy soil (4)	92.0	None	4	Neutral	Neutral	Neutral	Neutral	Neutral	Very slight, slight	Colorless	Colorless	Pale yellow	0.92	30.7	0.14	0.9	None	1: 34.1
3192	Good sandy soil (4)	91.4	None	4	Neutral	Slightly alkaline	Neutral	Slightly alkaline	Neutral	Rather strong	Colorless	Colorless	Pale yellow	0.94	31.3	0.25	1.7	None	1: 18.4
4382	Clay soil, poor in humus (8)	86.2	None	0	Neutral—slightly alkaline	Neutral—slightly alkaline	Neutral—slightly alkaline	Neutral—slightly alkaline	Neutral	Rather strong	Colorless	Colorless	Pale yellow	0.78	26.0	0.15	1.1	None	1: 23.6
2881	Good sandy soil, rather rich in humus (5)	94.2	Very slight	1	Neutral—slightly alkaline	Neutral—slightly alkaline	Neutral—slightly alkaline	Neutral—slightly alkaline	Slightly alkaline	Slight	Colorless	Colorless	Colorless	1.19	39.7	0.05	0.3	None	1: 132.3
3079	Loam soil, poor in humus	91.8	None	4	Neutral—slightly alkaline	Neutral—slightly alkaline	Neutral—slightly alkaline	Neutral—slightly alkaline	Neutral	Rather strong	Pale yellow	Colorless	Pale yellow	0.78	26.0	0.10	0.7	None	1: 37.1
2980	Good sandy soil, rich in humus (6)	92.0	None	4	Neutral—slightly alkaline	Neutral—slightly alkaline	Neutral—slightly alkaline	Neutral—slightly alkaline	Alkaline	None	Colorless	Colorless	Yellow	0.57	19.0	0.05	0.3	None	1: 63.3
4233	Good sandy soil (4)	88.0	Slight	4	Slightly alkaline	Neutral—slightly alkaline	Neutral—slightly alkaline	Neutral—slightly alkaline	Slightly alkaline	Very slight, none	Colorless	Colorless	Pale yellow	0.86	28.7	0.12	0.8	None	1: 35.9
2997	Sandy loam soil (5)	91.8	Very slight	4	Slightly alkaline	Slightly alkaline	Slightly alkaline	Slightly alkaline	Alkaline	None	Colorless	Colorless	Yellow	0.48	16.0	-0.01 (-0.1)	None	None	
3065	Sandy loam soil, poor in humus (4)	91.6	Slight	4	Slightly alkaline	Slightly alkaline	Slightly alkaline	Slightly alkaline	Alkaline	None	Colorless	Colorless	Yellow	0.25	8.3	-0.09 (-0.6)	None	None	
3011	Dark sandy soil, rather rich in humus (5)	86.0	Very slight	3	Slightly alkaline	Slightly alkaline	Slightly alkaline	Slightly alkaline	Alkaline	None	Colorless	Colorless	Yellow	0.63	21.0	**	None	None	
B	Loam soil (6)	88.0	Very slight	4	Slightly alkaline	Slightly alkaline	Slightly alkaline	Slightly alkaline	Slightly alkaline	None	Colorless	Colorless	Yellow	0.54	18.0	±0.00	±0.0	None	
4238	Good sandy soil, rich in humus (7)	84.2	Very slight	4	Slightly alkaline	Slightly alkaline	Slightly alkaline	Slightly alkaline	Alkaline	None	Colorless	Colorless	Pale yellow	0.64	21.3	0.03	0.2	None	1: 106.5
4237	Good sandy soil, rich in humus (7)	87.4	Strong	4	Slightly alkaline	Slightly alkaline	Slightly alkaline	Slightly alkaline	Alkaline	None	Colorless	Colorless	Yellow	0.28	9.3	-0.05 (-1.3)	None	None	
3001	Sandy loam soil, poor in humus (4)	96.0	Very slight	4	Alkaline	Alkaline	Alkaline	Alkaline	Alkaline	None	Colorless	Colorless	Yellow	0.38	12.7	-0.05 (-0.3)	None	None	
2179	Loam soil (6)	90.4	Very slight	4	Alkaline	Alkaline	Alkaline	Alkaline	Alkaline	None	Colorless	Colorless	Yellow	0.38	12.7	±0.00 (±0.0)	None	None	
3142	Loam soil, rather rich in humus (6)	85.6	Slight	4	Alkaline	Alkaline	Alkaline	Alkaline	Alkaline	None	Colorless	Colorless	Yellow	0.24	8.0	0.05	0.4	None	1: 20.0

TABLE 11 (Cont.)

SOIL SAMPLE NUMBER	ORDINARY CON- DITION OF THE SOIL	PER CENT DRY MATTER IN THE SOIL	ACID EFFER- VESCENCE	AZOTOBACTER VEGETATION		PER CENT AMMONIUM CHLORIDE-SOLU- BLE LINE	REACTION FOR LITMUS SOLUTION		REACTION FOR LITMUS PAPER (SOIL FOR- MIDGE)	REACTION FOR LITMUS IN MIXTURE OF TASSIUM CHLORIDE SOLUTION	REACTION FOR POTASSIUM IODIDE AND POTASSIUM IODATE (BAUMANN AND GULLY'S METHOD)		REACTION FOR P-NITRO- PHENOL	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS 1/10 N ACID			SIZE OF THE GELATINOUS PRECIPITATE APPEARING WHEN KCl EXTRACT IS NEUTRALIZED WITH SODIUM HYDRAE	RELATION BETWEEN THE AMOUNT OF ACID FREED BY THE POTASSIUM CHLO- RIDE AND THE CALCIUM ACETATE METHOD	
				PER CENT DRY MATTER IN THE SOIL			Per 3 grams air-dry soil	Per 100 grams air- dry soil			Potassium acetate method	The absolute acid- ity per 100 grams air-dry soil							
				In moist condition	In air-dry condition														
1. Field Soils																			
4014	Good sandy soil (4)	89.6	Very slight	4	Alkaline	Alkaline	Alkaline	Alkaline	Alkaline	None	Colorless	Yellow	0.18	6.0	-0.10	(-0.7)	None		
4018	Sandy loam soil (5)	87.2	Very slight	4	Alkaline	Alkaline	Alkaline	Alkaline	Alkaline	None	Colorless	Yellow	0.22	7.3	-0.10	(-0.7)	None		
4167	Clay soil, rather rich in humus (9)	83.6	Strong	4	Alkaline	Alkaline	Alkaline	Alkaline	Alkaline	None	Colorless	Yellow	0.26	8.7	-0.05	(-0.4)	None		
4276	Good sandy soil (4)	95.2	Very Strong	4	Strong alkaline	Strong alkaline	Strong alkaline	Alkaline	Alkaline	None	Colorless	Yellow	0.12	4.0	-0.05	(-0.3)	None		
4245	Sandy loam soil (5)	91.2	Very strong	4	Strong alkaline	Strong alkaline	Strong alkaline	Alkaline	Alkaline	None	Colorless	Yellow	0.22	7.3	-0.05	(-0.3)	None		
2. Peat Soils††																			
1	Raw high-bog peat from "Kude-mose" near Herning	85.7	None	0.0.14	Strong acid	Strong acid	Strong acid	Acid	Acid	Very strong	Light brown	Blue	Colorless	1.90	1140	3.92	235	Quite large	1: 4.9
2	Raw high-bog peat from "Vejen Mose"	87.9	None	0.0.21	Strong acid	Strong acid	Strong acid	Acid	Acid	Very strong	Dark brown	Blue	Colorless	2.12	1272	5.12	307	Large	1: 4.1
3	Raw high-bog peat from "St. Vild-mose"	84.4	None	0.0.61	Strong acid	Strong acid	Strong acid	Acid	Acid	Very strong	Medium brown	Blue	Colorless	2.16	1296	3.33	200	Quite large	1: 6.5

4	Peat from the transition belt between high-bog and low-bog in "St. Vildmose," Gjelleruplund near Herning	82.4	None	4/2.16	Neutral	Neutral	Neutral—slightly alkaline	Slightly alkaline	None	Colorless	Colorless	Pale yellow	0.64	384	0.37	22	None	1:17.5
5	Low bog peat from "St. Vildmose," Gjelleruplund near Herning	56.7	None	0/1.46	Acid	Acid	Acid	Slightly acid	Strong	Yellow	Blue	Colorless	1.50	900	0.87	52	None	1:17.9
6	Low-bog from Brogaard near Vejen	87.9	None	0/2.19	Slight acid	Neutral—slightly acid	Acid	Neutral	Strong	Very pale yellow	Pale blue	Colorless	1.02	612	0.37	22	None	1:27.8
7	Low-bog peat from Tylistrup	74.2	None	0/1.39	Acid	Acid	Acid	Acid	Very strong	Yellow	Blue	Colorless	1.86	1126	1.07	64	None	1:17.6

* In the case of peat soils: per 1/6 gram oven-dry soil.

† In the case of peat soils: per 100 grams oven-dry soil.

‡ In the case of peat soils: per 5 grams oven-dry soil (= half of the liquid).

** There was too little soil to make a quantitative determination. A specimen with a smaller amount of soil (14 grams in 70 cc. of the liquid) showed, however, that the potassium chloride extract gave a distinct alkaline reaction for phenolphthalein.

†† All the soil samples come from the upper 30 cm. peat layer.

To illustrate the matter further, observations were made of the size of the gelatinous precipitate appearing when potassium chloride extract is saturated with sodium hydroxide. In connection with these investigations, with the help of a strip of red and of blue litmus paper placed over the surface of the solution before filtering, and left for about an hour, observations were made of the reaction of the potassium chloride solution after it had stood five days with the soil. The results of the investigations are given in table 11.

As litmus is the indicator which has hitherto been used in qualitative investigations of the reaction of the soil made by the author, the results obtained from them are used as a basis for comparison. As was the case in earlier investigations [see further (10, p. 431)] the reactions from the litmus solution are expressed in the following way:

Strongly acid (yellowish-red color).

Acid.

Slightly acid.

Neutral—slightly acid.

Neutral (violet color).

Neutral—slightly alkaline.

Slightly alkaline.

Alkaline.

Strongly alkaline (strong blue).

Litmus-test. As is stated before, investigations have been made with the use of litmus solution and litmus paper. With the former we have also made an investigation comparing the reaction of the soil specimens when in the moist condition in which they were at the beginning of the experiment, and in an air-dry condition. As table 11 shows, the drying has had no effect upon the reaction which may be positively stated—in any case only shades of distinction (to the one side or to the other). Therefore, in making qualitative reaction-determinations it seems to be a matter of indifference whether the soil is used in a moist or an air-dry condition, and the somewhat larger amount of CO_2 which we take for granted is present in moist soil, has no appreciable influence on the determinations.

In many soils, and especially in the loam and clay soils, the reactions in the litmus solutions appear sharpest and most distinct when dry soil is used, for the liquid becomes more quickly and easily clear.

The presence of a larger amount of fine particles floating about gives the litmus solution a more reddish color than the reaction itself causes, and on this account the determination is somewhat uncertain. In such cases the litmus-paper test is to be preferred. On the whole the results obtained from this method correspond satisfactorily with those gained by using the litmus solution; but the latter is generally better able to express small differences in the reaction of the soil. As the strongly acid reaction (the characteristic yellowish-red color in the litmus solution), does not appear at all in the paper-test, the litmus solution must be considered to give more complete

information about the reaction of the soil than litmus paper, and as the former method is quicker, which is of no small importance when examinations are to be made on so large a scale as the case is here in Denmark,¹⁵ that method is on the whole to be preferred. In cases where a doubt arises (very opaque liquids, see above), the litmus paper test should always be used for control, and as it does not require much practice for making a correct valuation of the color changes, it would perhaps also be the best method to use when the determinations are made by persons of little experience.

Daikuhara's nitrite-method. As the table shows, this method is very sensitive to small changes, all the soils which in the litmus-test have been proved more or less acid (strongly acid—slightly acid), have caused a strong blue color to appear on the potassium iodate starch paper. The same is true of various neutral soils both with and without *Azotobacter* vegetation. First, when litmus shows a decidedly alkaline reaction (slightly alkaline—strongly alkaline), the blue color ceases to appear on the paper. Therefore, according to the investigations previously made of the lime-requirement of the soil (10), we find a large number of non-lime-requiring soils which tested by Daikuhara's method give an acid reaction.¹ On the other hand, it is fairly safe to say that all the soils which do not color potassium iodate starch paper blue have no lime-requirement. Yet, as all these soils, either by the litmus test alone, or in connection with the *Azotobacter* test prove to be rather rich in basic substances, the nitrite method does not fill any particular need, either in making a general determination of the reaction of the soil or of its lime-requirement. Yet to have demonstrated the ease and speed with which this reaction takes place, is of interest in another connection, for it suggests that to use nitrites as nitrogen fertilizers, which has often been under consideration, would for many types of soil risk a considerable nitrogen loss.

The iodine method according to Baumann and Gully. The results of the determinations based on the Baumann-Gully method on the whole agree well with the results of the reaction-determinations made by the litmus-test. All the soils which have shown a distinct acid reaction for litmus have caused a distinct yellow coloring of the solution used. In the case of the neutral soils the liquid is either slightly yellow or colorless, and no distinction can be made between neutral soils with and without *Azotobacter* vegetation. In using soils that show a positive alkaline reaction for litmus solution (slightly alkaline—strongly alkaline), no iodine has been freed.

Nor does this method give information as to the reaction of the soil other than has appeared from the litmus test, and as the method is rather detailed, and the reagents very sensitive to the CO₂ in the air, we need not expect that it will play an important part in making a qualitative determination of the reaction of the soil.

P-nitrophenol method. The results of the reaction-determinations when this

¹⁵ In the years 1910–1916, using the combined litmus and *Azotobacter* test (1 to 1) suggested by the author, about 40,000 soil specimens were examined.

indicator is used agree in general very well with those with the litmus solution. The soils which show acid reaction for litmus have either—and this is usually the case—decolorized the solution, or else caused no change in the original very slightly yellowish tinge of the liquid. In the case of soils showing a neutral reaction for litmus, there is a distinct difference between the two groups, with and without *Azotobacter* vegetation, for the former colors the liquid somewhat more yellow than the latter. There are, however, a few exceptions to this rule, the soils which for litmus are decidedly alkaline show, with one or two exceptions, among the slightly alkaline soils, the very strongest possible yellow color (greenish-yellow). The use of p-nitrophenol must on the whole be considered to give very good information as to the reaction of the soil, and in certain cases where the litmus test has shown a neutral reaction, this indicator may be used with advantage in supplementary investigations.

However, litmus has this one advantage over all other indicators—it shows distinct changes on both sides of the neutral point, and on this account no other indicator can supplant it in ordinary qualitative determinations of the reaction of the soil.

In addition to these named, experiments have been made with various other indicators—for example “neutral red,” which like litmus has its turning-point in the neighborhood of the true neutral point. Unfortunately, this indicator can not be used in reaction-determinations of the soil, as it is to a larger or smaller extent discolored by it.

In connection with these investigations, an experiment has been made with a colorimetric measurement of the hydrogen-ion concentration in the filtrates from the mixtures of field soils and water. The experiment has given negative results in that there seems to be an indication that the colorimetric method cannot generally be used in determining hydrogen-ion concentration in the watery soil-extracts, a condition which must be largely explained by an insufficient appearance of “buffers” [see further, S. P. L. Sørensen (3, p. 17)]. There is a large quantity of these present in the soil itself. In a colorimetric determination of the reaction of the soil, we are reduced to working with mixtures of soil and water, and an exact determination of the hydrogen-ion concentration in watery soil-extracts can, therefore, in general be made only by the electro-metrical method.

In connection with the investigations of the methods for a qualitative determination of the reaction of the soil referred to above, quantitative determinations of the ability of the soil to free acid have been made, the potassium chloride method suggested by Daikuhara being used in part, and the calcium acetate method in part.

The main results of the investigations of mineral soils are grouped together in the summary in table 12, and in figure 4, which deals particularly with the soils with which both the calcium acetate and the potassium chloride method have been used.

As this summary shows, the ability of the soil to free acid, measured ac-

cording to both methods, is, on the average, greatest in those soils giving an acid reaction for litmus, and decreases with decreasing acidity and increasing alkalinity (for litmus). But aside from this agreement in the principal characteristic, the two methods show very important and characteristic differences in the results of the investigations.

First, in considering the relation of the soils to the potassium chloride solution we find that *only those soils showing a decidedly acid reaction for litmus are able to free acid from this solution to an appreciable extent*; and it is important to note (table 11), that this ability, though varying greatly in degree, is yet present in all soils showing an acid reaction.¹⁶ The amount of acid freed from the potassium chloride solution decreases greatly as the neutral reaction

TABLE 12

Relation between the reaction of mineral soils for litmus and their ability to free acid

REACTION FOR LITMUS	NUMBER OF SOILS	ACID FREED, EXPRESSED IN CUBIC CENTIMETERS OF ACID 1/10 N PER 100 GRAMS AIR-DRY SOIL										RELATION BETWEEN THE AMOUNT OF ACID FREED BY THE POTASSIUM CHLORIDE METHOD AND THAT FREED BY THE CALCIUM ACETATE METHOD
		Acetate method				Potassium chloride method						
		Largest amount of acid freed	Smallest amount of acid freed	Difference between the largest and smallest amounts of acid freed	Average	Largest amount of acid freed	Smallest amount of acid freed	Difference between the largest and smallest amounts of acid freed	Average			
Strongly acid.....	13	150.0	46.0	104.0	82.9	150.3	5.7	144.6	35.6	1: 2.3		
Acid.....	10	100.7	43.3	57.4	66.8	43.3	2.3	41.0	10.3	1: 6.5		
Slightly acid.....	9	56.7	30.7	26.0	48.2	10.4	1.1	9.3	3.8	1: 13		
Neutral—slightly acid.....	9	63.3	22.3	41.0	43.5	5.3	0.6	4.7	1.9	1: 23		
Neutral.....	18	70.3	17.3	53.0	33.8	1.7	0.3	1.4	0.8	1: 42		
Neutral—slightly alkaline.....	4	39.7	19.0	20.7	27.7	1.1	0.3	0.8	0.6	1: 46		
Slightly alkaline.....	6	28.7	8.3	20.4	16.9	0.8	-0.6	1.4	0			
Alkaline and strongly alkaline.....	8	12.7	4.0	8.7	8.3	0.4	-0.7	1.1	-0.3			

is approached, and at that point the amount of acid freed is so small that in the case of field soils a quantitative determination is inaccurate. (It must be remembered that the figures expressing the absolute acidity are obtained by multiplying the values found with the factor 3.) *The variations in the ability of this group of soils to free acid as well as in the following groups are very small.*

¹⁶ This close agreement between the results of the potassium chloride and the litmus methods may be said to make even more probable the supposition (page 144) that the ability to color litmus red (in opposition to Baumann and Gully's opinion) is caused by the presence of *truly acid-reacting substances* in the soil in question.

G. Fischer reaches a similar result by another method. By an electro-metric measurement of the hydrogen-ion concentration in various peat soils he proves that in those showing an acid-reaction for litmus there is a considerable hydrogen-ion content.

The investigations of peat soil made (table 11, show that high-bog peat specimens have a far greater ability to free acid from potassium chloride than low-bog peat specimens, even though the latter show an acid reaction for litmus. When an acetate solution is used, the difference between the amount of acid freed by high-bog peat and that freed by low-bog peat is far less apparent, and one of the low-bog peat specimens (no. 7) even shows almost as great an amount of acid freed as the high-bog peat specimens.

The slightly blue color in the litmus solution (slightly alkaline reaction—a reaction almost coincident with the absolute neutral point, which is charac-

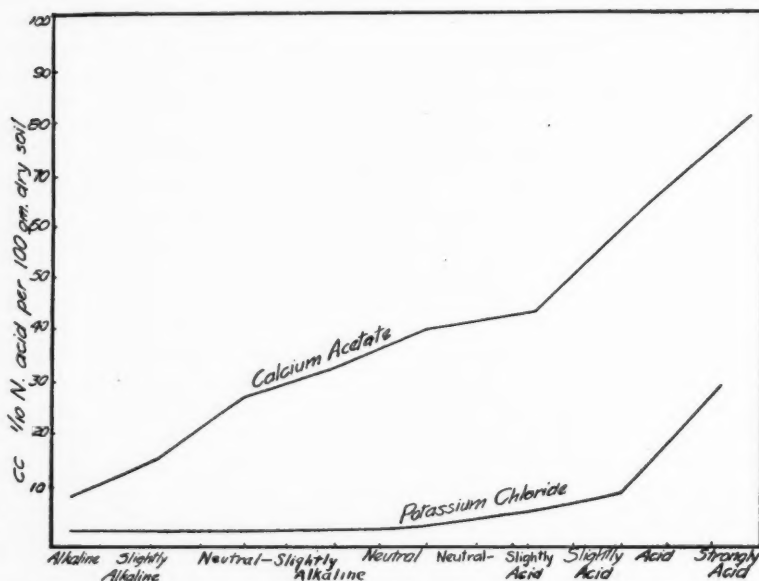


FIG. 4. DIAGRAM SHOWING THE RELATION BETWEEN THE REACTION OF THE SOIL FOR LITMUS AND ITS ABILITY TO FREE ACID

terized by the presence of an equal number of H and OH-ions) indicates that acid is no longer being freed from the potassium chloride solution, and where the reaction is more alkaline (for litmus), the potassium chloride solution is in almost every instance distinctly alkaline (for phenolphthalein).

The results at hand may, with considerable certainty, be said to suggest that the freeing of acid from the potassium chloride solution is alone determined by the presence of *truly acid-reacting substances* in the soil in question. This condition was already apparent in the results, shown in table 11, of the qualitative investigations of the reaction of the potassium chloride solution, which, after standing for five days with the soil, was tested with litmus paper.

These results agree very well with those from reaction-determinations made according to the normal litmus method.

As has been mentioned before, Daikuhara states that when a surplus of ammonium is added to the filtrate of the potassium chloride solution, which has stood with acid mineral soil, a gelatinous precipitate always appears. This is composed of aluminum—or (in certain instances), iron-hydroxide, and the proportion always bears a definite relation to the acidity of the solution. Therefore, he concludes that the acidity of mineral soils is solely dependent on the appearance of certain acid aluminum—or iron—compounds (acid silicates).

To throw further light on the question notes have been made of the size of the precipitate appearing when the potassium chloride solution is saturated with sodium hydroxide. The results appear in table 11.

As may be seen, *all strongly acid, and, moreover, the majority of acid or slightly acid, mineral soils, give a whitish gelatinous precipitate, whereas no investigation has ever shown this to be true of neutral or slightly alkaline soils.* The amount of the gelatinous precipitate increases with the increased acidity of the liquid (measured according to the potassium chloride method), and when the number expressing this is over 6, the precipitation has always taken place.

These observations seem to confirm Daikuhara's statements, even though they are unable to give positive assurance as to whether the acidity of the mineral soils depends, as that author claims, solely on the presence of substances of the above-mentioned kind.

In humus soils we notice that in neutralizing the extracts from the high-bog peat samples, a considerable gelatinous precipitate appears (in this instance reddish-brown in color), and that the amount of the precipitate (as in mineral soils) seems to bear a certain relation to the amount of acid freed from the potassium chloride solution. One would thus be inclined to suppose that the acidity of this type of soils depends to a large extent on acid iron compounds. Special research work on this point would have particular interest.

Low-bog peat specimens, which, as has been said, have a somewhat limited power to free acid from a potassium chloride solution, showed, after the potassium chloride extract had been neutralized, no gelatinous precipitation, even though the soil specimens themselves gave a decidedly acid reaction for litmus.

In addition to the determinations already mentioned, a determination has been made according to methods previously used (10), of the lime in peat soils which is soluble in ammonium chloride. As table 11 shows in the two humus types examined, no connection has been found between the acid freed from acetate or potassium chloride solution, and the content of lime soluble in ammonium chloride in the soil.

If we now examine the results from the acetate method, we will immediately see that these are far greater than those obtained from the potassium

chloride method. This is due to the fact either that in using the latter method one is unable to obtain as correct an expression for the absolute acidity of the soil as from the acetate method, or that the acid may be freed from the calcium acetate solution not only by the action of *truly acid-reacting substances*, but also by substances of another character.

In table 12 is a summary of the results of the investigations of mineral soils. From these statistics it appears that the values expressing the degree of acid obtained according to the acetate method, in contrast to those from the potassium chloride method, diminish regularly from acid to alkaline reaction, and that thus both neutral and alkaline soils have the power of freeing a considerable amount of acid from an acetate solution. Resulting from this the relation between the amounts of acid freed from potassium chloride and calcium acetate is far closer in distinctly acid than in approximately neutral soils.

This condition appears plainly in figure 4, showing the relation between the reaction of mineral soils for litmus, and the degree of acid freed from the two salt solutions named. While the curve representing the absorption of bases in the potassium chloride solution runs almost parallel with the abscissa axis until acid reaction begins and then rises quite sharply, the curve representing the calcium acetate solution never reaches the abscissa axis, and rises gradually. A closer examination of the single determinations made, calcium acetate solution being used, table 11, shows that the relation between the acid freed and the reaction of the soil is far from being as regular as this diagram would seem to indicate. While the variation in the ability of neutral soils to free acid from potassium chloride solution is always very small, and the amount of acid freed is always much less than in distinctly acid soils, when calcium acetate solution is used with neutral soils the variations in the amount of acid freed are very large, and neutral field soils quite frequently free even a larger amount of acid than very distinctly acid-reacting soils.

These characteristic differences in the results obtained from the two methods are presumably due to the fact that the absorption of bases, and the consequent freeing of acid from the calcium acetate solution is not, as is the case with potassium chloride solution, solely caused by the presence of *truly acid-reacting substances*, but also by the presence of substances of quite another character, whether these be adsorptively unsaturate colloids, or other non-acid reacting substances with the ability to absorb bases from salts of weak acids.

In peat soils it is interesting to note (table 11) that in the relation between the two amounts of acid freed from the two liquids there is a characteristic difference between high-bog peat and low-bog peat, the relation being 4 to 5 times closer in high-bog peat than in low-bog peat.

As has been mentioned before (page 118), Daikuhara claims that by using his potassium chloride method one is able to express quantitatively the lime-

requirement of the soil. If his claim is correct, only those soils giving acid reaction for litmus (based on the investigations mentioned above) have a distinct lime-requirement while all neutral soils either have no lime-requirement whatsoever or a very small one.¹⁷ Previous investigations made by the author and O. H. Larsen (10) show that a large number of field soils with neutral reaction for litmus have a decided lime-requirement, and that when lime is added to these soils, sometimes a greater result is obtained than from the distinctly acid soils. In such instances, adding the 100 kgm. of carbonate of lime, which according to the results obtained from this method would usually suffice, is practically without effect. And too, with many of the distinctly acid soils, measuring the amount of lime according to the results of the potassium chloride method will give far too small an amount for practical purposes. For many decidedly acid soils, the figures expressing the absolute acidity are between 5 and 10, and in such cases, according to the method of computing given here, the addition of 600 to 1200 kgm. of carbonate of lime per hectare, should be sufficient to fulfill the lime-requirement in the soil. However (partly due to the fact that in the field it is impossible to mix the lime with the acid soil so thoroughly as in the retorts in the laboratory), and judging from practical experience and the results of the field experiments, such small amounts of lime are far too insignificant entirely to fulfill the lime-requirement of the soil.

However, even though by determining the acidity of the soil we are unable to state positively the extent of its lime-requirement, yet a quantitative acid determination can in many cases give suggestions as to the magnitude of this need, and there is no doubt that soil specimen no. 3313, showing an acidity content corresponding to ca. 150 cc. of 1/10 N acid per 100 grams of dry soil requires a considerable amount of lime for satisfying its lime-requirement, for according to this method of computing, it is necessary to add ca. 18,000 kgm. of carbonate of lime per hectare merely to neutralize the soil.

Of the methods which at the present time seem to give the best information in regard to the degree of the acidity of the soil, the potassium chloride method is the one most deserving of attention, and its use will in many instances be a great assistance in making a diagnosis of the condition of the soil.

It is generally supposed that a larger amount of lime is necessary for satisfying the lime-requirement of clay soils than of sandy soils. If this supposition is correct, we have reason to expect that the former soils within the single reaction groups (and the groups with and without *Azotobacter* vegetation) possess a greater ability to absorb bases than the latter.

To throw light on the matter the material at hand was treated as table 13 shows. This summary includes the results obtained from table 11, and in the

¹⁷ An amount of acid freed corresponding to 1 cc. 1/10 N acid for 100 grams soil will only require ca. 120 kgm. CaCO_3 for neutralizing the acid content in the upper 20 cm. per hectare (see further, page 145).

case of the acetate method those from table 6 as well. A distinction is made among 5 degrees of heaviness in soil, which in the last division of the table are grouped together in two classes—clay soil and sandy soil.

In looking over the results obtained from the acetate method, we see that the clay soil in all three reaction groups and in the groups with and without *Azotobacter* vegetation possesses, on the average, somewhat less ability to absorb lime than the sandy soils of the corresponding groups. In using the potassium chloride method the relation is quite the opposite, for the clay soils with acid reaction—or by the *Azotobacter* test—without the ability to cause *Azotobacter* development, possess on the average more than twice as great

TABLE 13
Comparison between the ability of clay and of sandy soils to free acids

CHARACTER OF THE SOIL	ACETATE METHOD										POTASSIUM CHLORIDE METHOD									
	Number of soils					Acid freed in cm. $\frac{1}{10}$ N acid per 100 gm. dry soil					Number of soils					Acid freed in cm. $\frac{1}{10}$ N acid per 100 gm. dry soil				
	Acid*	Neutral†	Alkaline‡	Without az. v. §	With az. v.	Acid	Neutral	Alkaline	Without az. v.	With az. v.	Acid	Neutral	Alkaline	Without az. v.	With az. v.	Acid	Neutral	Alkaline	Without az. v.	With az. v.
Clay soil.....	9	8	6	13	10	62.7	37.8	14.2	55.0	23.7	7	6	1	11	3	37.2	1.1	-0.4	24.2	0.3
Loam soil.....	7	4	3	8	6	65.2	33.4	17.5	60.6	26.4	5	3	2	6	4	20.6	0.6	0.0	17.3	0.3
Sandy loam.....	4	8	7	6	13	47.8	30.0	9.8	43.0	18.6	3	7	6	5	11	9.8	0.8	-0.3	6.2	0.2
Good sandy soil.....	11	13	8	16	82.1	41.0	15.9	72.7	25.0	10	11	5	15	11	12.6	0.9	-0.1	8.7	0.4	
Light sandy soil.....	11	11	1	21	2	67.8	37.5	21.1	53.1	32.5	7	4	0	11	0	11.5	2.6	—	8.3	—
Loam soil.....	20	20	16	27	29	60.6	33.8	12.9	54.0	22.0	15	16	9	22	18	26.2	0.9	-0.2	18.2	0.3
Sandy soil.....	22	24	9	37	18	75.0	39.4	16.5	61.5	25.8	17	15	5	26	11	12.1	1.3	-0.1	8.5	0.4

* Includes groups: Strongly acid, acid and slightly acid.

† Includes groups: Neutral-slightly acid, neutral and neutral.

‡ Includes groups: Slightly alkaline, alkaline and—slightly alkaline,—strongly alkaline.

§ az. v.—*Azotobacter* vegetation.

an ability to free acids as the sandy soils of these groups. In neutral and alkaline soils, and in those soils causing *Azotobacter* development, the ability to free acid from potassium chloride is, as has been mentioned before, so small that it is impossible to indicate the differences in the degree of this ability for various soils.

As the comparison made shows, a different result is obtained according to whether the calcium acetate or the potassium chloride method is used. It is impossible for the present to state which of these two methods can on the whole give the most helpful information as to the lime-requirement of the soil. With these data we are unable to verify the extent to which the above-named supposition that lime-poor clay soils require on the average a greater addition of lime than sandy soils is correct. It is indeed probable that the

supposition is correct in the case of mineral soils showing an acid reaction for litmus, for the results appearing from the potassium chloride method suggest decidedly that acid clay soils require on the average a far greater amount of basic substances to attain a neutral reaction than acid sandy soils.

III. SUMMARY OF THE MAIN RESULTS OF THE INVESTIGATIONS

As a result of the investigations made, it seems to be necessary to distinguish sharply between *the absolute acidity of the soil*, and *its ability to free acids* (absorb bases).

The majority of methods suggested for making a quantitative determination of the acidity of the soil give no information as to the content of *truly acid-reacting substances* in the soil, *i.e.*, substances which in solution cause a hydrogen-ion concentration greater than corresponds to the value 10^{-7} ; but only of its ability to absorb bases, which is partly determined by the presence of acid-reacting substances, and partly by the presence of non-base saturate colloids, or other non-acid reacting, but base-absorbing substances.

We still lack a method for making a positive quantitative determination of the acidity of the soil, in the meaning of the word given above, even though the methods suggested by Hopkins and his collaborators, and later by Daikuhara with the use of chloride solutions, seem in many cases to give valuable information on this point.

In determining the ability of the soil to absorb bases, a method based on Baumann and Gully's principles, in which acetates are employed, should be preferred to Tacke and Süchting's method, not only because it gives results which are more certain and approach the absolute values more closely, but also because the investigations may be made far more quickly than according to the latter method.

Baumann and Gully's claim that no free acids exist in sphagnum peat is probably incorrect. The results of the investigations made here must be understood to mean that the ability to absorb bases characteristic of this type of soil, as well as of others which show an acid reaction for litmus, is in every instance partly dependent on the appearance of *truly acid-reacting substances*, a result which coincides fairly well with the claim made in a former paper (9), that raw high-bog peat contains a considerable amount of such substances. The further claim made by the above-mentioned scientists, and later repeated by Ramann, that the ability of a soil to color a neutral litmus solution red need not be an expression for the presence of free acids in it, but is solely caused by the ability of soil colloids to free acids from neutral salts, is also incorrect, for it has been proved that there is no closer connection between the ability of the soil to free acids, determined according to the calcium acetate method, and its reaction for litmus, and furthermore, that many of the soils which when tested by this method show a considerable ability to free acids, show a neutral or slightly alkaline reaction for litmus. The fact

that it is only those soils with a distinct acid reaction for litmus which are able to an appreciable extent to free acid in a potassium chloride solution, must, on the contrary, be said to indicate that the ability of the soil to color neutral litmus solution red is due to the presence of truly acid-reacting substances in the soil in question. The importance of the litmus test in making soil investigations, especially in examining the requirement of the soil for basic substances, which in practice is its lime-requirement, is therefore easily understood.

A determination of the base-absorption power of the soil is not sufficient for determining its lime-requirement, for it has been found that many of the soils, which, based on former investigations, were considered to require lime (such as those not causing *Azotobacter* vegetation under the *Azotobacter* test) possess less power to free acids in a calcium acetate solution than those which do not require lime (such as those causing *Azotobacter* vegetation under the *Azotobacter* test). Nor can we expect a determination of the acidity of the soil to give positive information as to whether or not it requires lime. As has been proved previously, all mineral soils showing an acid relation for litmus have a large lime-requirement. In such instances a quantitative determination of the acid content of the soil which expresses the amount of lime necessary for neutralizing the acid present, will also give reliable though insufficient information as to the degree of the lime-requirement of the soil. However, we must remember that many soils which show a neutral reaction for litmus, have a decided lime-requirement and in such cases it is impossible to use the acidity determination in determining the degree of the lime-requirement of the soil.

At this point it is well to emphasize the fact that the qualitative determination of the lime-requirement, according to the combined litmus and *Azotobacter* tests in general use in Denmark at present, can to a certain extent give information as to the degree of the lime-requirement of the soil. Acid-reacting soils which only to become neutral require a certain amount of lime, doubtless need, on the average, a far more considerable lime addition to fulfill their lime-requirement than neutral lime-requiring soils without *Azotobacter* vegetation, which presumably in the majority of instances should be and are content with the addition of a proportionately small amount of lime. To elucidate further the question which has great practical importance, investigations must be made in connection with a larger number of field experiments in the use of lime.

As the author has previously stated, it is probable that the question of the lime-requirement of the soil is predominantly a question of the presence or absence of certain easily-decomposed acid-saturating calcium (or magnesium) compounds. If the problem is such, the efforts to find a quantitative expression for the lime-requirement must be in the direction of methods which can express the amount of lime-fertilizer necessary for supplying the soil with a

sufficient quantity of such compounds. To what extent there are possibilities for finding such a method, and whether or not it should rest upon a chemical or a biological foundation, must for the present remain unanswered.¹⁸

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¹⁸ Since the above article appeared, H. Kappen has published an interesting investigation of the reaction of the soil (Studien an sauren Mineralböden aus der Nähe von Jena.—*In Landw. Vers. Stat.*, Bd. 88, 1916, p. 13), of which, unfortunately, no account could be taken.—H. R. C.

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